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FIELD ARTILLERY SCHOOL
Fort Sill, OK 73503

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FIELD ARTILLERY POSITION/NAVIGATION OPERATIONAL ANALYSIS (FA POS/NAV)

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Final Report

September 1982

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This analysis was conducted by Directorate of Combat Developments, United States Army Field Artillery School (USAFAS), Fort Sill, Oklahoma.

The findings and recommendations of this study are those of the Commandant, USAFAS. They are based on data gathered by USAFAS from requirements documents, specifications and performance reports for survey equipment currently fielded, for other position/navigation systems under development and the estimated performance of equipment for which requirements documents are being drafted.

The USAFAS analysis team consisted of Roy E. Penepacker and John L. Horn.

Mr. Gene L. Lacy, Chief, Target Acquisition Specialist Branch, and SSG James Lewis, Instructor, Target Acquisition Department, made a significant contribution to the sound ranging accuracy analysis in chapter 5.

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The report contains an operational analysis, assisted by modeling, when appropriate, in sufficient detail to formulate recommendations for the architecture of FA survey systems during the period 1982-96. The recommendations for the 1996 time frame include a mix of: Position Location Report System/Joint Tactical Information Distribution Hybrid System(PJH); Global Positioning System (GPS); Position and Azimuth Determining System (PADS); on-board fire control/positioning systems; and small lightweight azimuth determining systems.

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CHAPTER 1

INTRODUCTION

1-1. PURPOSE. The purpose of this study is to determine the architecture or the Field Artillery survey system for the 1986-96 time frame.

1-2. SCOPE. The study focuses on the positioning and orientation requirements for a division slice of the 1986 force structure. The Division 86 organization is used as the base case to examine the capability of the survey system, on-board fire control systems, and position/navigation systems to satisfy operational requirements.

1-3. ESSENTIAL ELEMENTS OF ANALYSIS.

a. What is the FA survey requirement for the 1986-96 time frame? What is the required accuracy? Responsiveness?

b. What is the 1986 survey system and does it meet 1986-96 requirements? If not, what are the shortfalls?

c. What alternative survey systems are available in the 1986-96 time frame?

d. How will each alternative survey system improve the performance of the 1986 survey system?

e. What trade-offs are available?

f. What is the preferred survey architecture for the 1986-96 time frame?

1-4. METHODOLOGY.

a. The division slice of systems which require orientation and position data are presented, followed by the accuracy and response requirements for each system.

b. The division survey system and alternative systems addressed in this study are described and the operational concepts for their use are presented.

c. The base case and alternative systems are analyzed with respect to each user's requirements for accuracy of positioning and orientation data and the time survey data must be available after occupation of position. The analysis is conducted in two parts: a subjective analysis of the base case and alternative systems to select the most appropriate systems for each user; and, an analytical analysis to determine the preferred system for each user.

d. The preferred systems are summarized, trade-offs, if any, determined, uncertainties identified and a system architecture described.

1-5. MEASURES OF PERFORMANCE/EFFECTIVENESS.

a. Measures of Performance.

(1) Accuracy. The measure of a candidate survey subsystem's ability to accurately perform the tasks required for positioning and orienting FA systems. Horizontal positioning accuracies are measured in terms of circular probable error in meters (CEPm). Vertical positioning accuracies are measured in terms of probable errors in meters (PEm). Azimuthal orientation accuracies are measured in terms of probable error in mils (PEø).

(2) Responsive Time. The measure of a candidate survey subsystem's ability to perform the tasks required for positioning and orientation of FA systems in a timely manner. Responsiveness is measured in minutes.

b. Measures of Effectiveness (MOE).

(1) MOE #1 = Survey CEP (SCEP). The amount of "on-target" error introduced by the positioning and orientation of an FA system when that system becomes involved in a subsequent fire mission. (see para 5-2a)

(2) MOE #2 = First-Round CEP (FRCEP). The total delivery error of the initial adjust round on a ground observer "adjust" mission. The ground observer's self-location error (his target location error relative to self) and weapon system delivery errors all contribute to FRCEP. (see para 5-2b)

(3) MOE #3 = One-Round Adjust CEP (ORCEP). The total delivery error of a fire-for-effect volley center after one round of adjustment. (see para 5?b)

(4) MOE #4 = Expected Fractional Casualties (EFC). The expected fraction of target area elements destroyed for a "standard" artillery mission. (see para 5-2c)

1-6. ASSUMPTIONS

a. The PADS will be available in sufficient quantities to equip the FY 86 force structure and its performance characteristics are as stated in the First Article Inspection Report for PADS. MERADCOM, May 1981.

b. The Survey Electronic Distance Measuring Equipment-Medium Range (SEDME-MR) will be fielded in 1984 and will become the standard distance measuring equipment for conventional survey parties.

c. The Multiple Launch Rocket System (MLRS) will be fielded in the FY 83 timeframe with an on-board Stabilized Reference Platform/Position Determining System (SRP/PDS) capable of providing orientation data of sufficient accuracy to support firing operations.

d. The Fire Support Team Vehicle (FISTV) will be fielded in FY 85 and will include an on-board North Seeking Gyro (NSG) capable of providing orientation data of sufficient accuracy for target acquisition operations.

e. The Field Artillery Meteorological Data System (MDS) will be fielded in FY 85.

f. The Position Location Reporting System (PLRS) will be fielded in limited quantities in FY 86 and will perform as stated in the Joint Services Operational Requirement (JSOR) for PLRS, dated 6 August 1976. The PLRS will be product improved and fielded as the PLRS/JTIDS Hybrid System in FY 87.

g. The Global Positioning System (GPS) will be fielded in FY 88 and will perform as stated in the Required Operational Capability for GPS, dated 22 March 1979.

h. The Azimuth Measuring Device (AMD) will be fielded in 1989 and the performance characteristics stated in the Draft Required Operational Capability for an AMD, USAFAS, 5 June 1981 will be achieved.

i. The Automatic Gun Positioning System (AGPS), a part of the M109A3 Howitzer Product Improvement Program, will be fielded in 1987. A similar system will be applied to the M110A2 Howitzer in 1985 or later.

1-7. CONSTRAINTS. This analysis is an operational analysis of survey operations, assisted by modeling, where appropriate, in sufficient detail to formulate valid findings and recommendations.

CHAPTER 2

MISSION NEEDS

2-1. SCOPE. The division slice of FA weapons, target acquisition and support systems which require position and orientation data are described briefly, followed by specific position and orientation data requirements and a discussion of the importance of the survey mission to the overall FA mission.

2-2. FORCE STRUCTURE. The study addresses position and orientation data requirements for the following division slice of FA systems. The system name, number of elements in the system/division and status (fielded/development) are listed at Table 2-1.

Table 2-1. Division slice of FA systems

SYSTEM	ELEMENTS	STATUS
1. Ground Observers	Three platoon forward observers and one FIST HQ per infantry FIST.	Fielded
	One FIST HQ per armor, armored cavalry FIST.	Fielded
	Four observation sections per target acquisition battery.	Fielded
2. Ground Laser Locator Designator (GLLD), AN/TVQ-2	One per FIST HQ and separate observation and lasing team in all divisions.	
	Note: The GLLD is mounted in the FISTV where authorized.	
3. Fire Support Team Vehicle (FISTV)	One per mechanized infantry, armor and armored cavalry FIST HQ	IOC FY 85
	One per separate observation/lasing team in mechanized infantry and armored divisions.	IOC FY 85
4. Sound/Flash Ranging Platoon	Two platoons per target acquisition battery (TAB).	Fielded
5. Remotely Piloted Vehicle (RPV)	Four RPV sections per division.	FY 87
6. Moving Target Locating Radar (MTLR) AN/TPS-25A/58	One section per target acquisition battery (TAB); one TAB per division.	Fielded
7. FIREFINDER Radar	Three mortar locating radar (MLR), AN/TPQ-36, per TAB.	Fielded
	Two weapon locating radar (WLR), AN/TPQ-37, per TAB.	Fielded
8. Meteorological Data System (MDS)	Three sections per division.	FY 85*
9. Howitzer Battery	Heavy Divisions.	
	Two four-howitzer platoons per direct support battery/three batteries per battalion.	FY 87**

SYSTEM	ELEMENTS	STATUS
	Two four-howitzer platoons per general support battery/two batteries per battalion.	FY 87*
	Light Divisions.	
	Two four-howitzer platoons per direct support battery/three batteries per battalion.	FY 87*
10. Multiple Launch Rocket System (MLRS)	One battery (three platoons of nine launchers) per heavy and light division.	FY 83
	One battalion (three batteries, as above per corps (division slice-one battery).	FY 85
11. LANCE	One battalion (three batteries, two launchers each, per corps, division slice-one battery).	Fielded

* - Current GMD authorization is one per division and one per FA Bde.

** - Howitzers currently fielded as follows:
105/155mm - six howitzer batteries
203mm - four howitzer batteries

2-3. ACCURACY REQUIREMENTS. System position and orientation accuracy requirements are listed at table 2-2. Systems are listed in order of decreasing orientation accuracy required. Accuracy requirements are based on QSTAG 269, Artillery Survey Accuracy Criteria, as amended 3 September 1981, and subsequent USAFAS modifications. These modifications changed the QSTAG requirement for horizontal positioning of the WLR/MLR from 17.5/35.0 meters CEP to 10 meters CEP and the vertical control requirement for MDS from 3 to 10 meters PE.

Table 2-2. Orientation and position accuracy requirements

SYSTEM	Survey Accuracy Orientation (PE)(MILS)	Hor Position (CEP)(Meters)	Vert Position (PE)(Meters)
WLR-AN/TPQ-37	0.15	10.0	3
MLR-AN/TPQ-36	0.30	10.0	10
RPV	0.50	20.9	10
LANCE	0.30	35.0	10
Howitzers	0.30	17.5	10
MLRS*	1.0	20.0	10
MTLR-AN/MPQ-25/58	3.0	43.6	30
MDS	9.0	113.4	10
Observers/GLLD	10.0	87.2	20
Sound Ranging	NA	0.9	10

*Not listed in QSTAG. Requirement stated by TSM, MLRS.

2-4. RESPONSIVENESS. The survey system must provide orientation and position data, within the time stated in table 2-3, to prepare the system for operation. Response times are listed in order of lowest to highest response time required. When the survey data is not available within the stated response time the system reverts to hasty survey methods to obtain the required orientation and position data.

Table 2-3. System response time requirements

SYSTEM	TIME(MIN)	REMARKS
MLRS	0.0	System Specification
LANCE	0.0	ARTEP Requirement
Self-Propelled Howitzers	0.5	ARTEP Requirement
Ground Observers w/o GLLD	2.0	Derived from ARTEP Requirements
FISTV	3.0	System Specification
Towed Howitzers	4.0	ARTEP Requirement
Ground Observer w/GLLD	5.0	GLLD Set-Up Time
MDS	5.0	RDF Antenna Set-Up Time
Mortar Locating Radar- AN/TPS-36	15.0	ARTEP Requirement
Weapon Locating Radar- AN/TPS-37	30.0	ARTEP Requirement
RPV	30.0	System Specification
Ground Surveillance Radar- AN/MPQ-58	30.0	ARTEP Requirement
AN/MPQ-25	60.0	ARTEP Requirement (two masks)

2-5. SURVEY DOCTRINE. Field Artillery doctrine stresses the timely and accurate delivery of fires to meet the requirements of supported units. The field artillery survey mission is to place all target acquisition equipment, firing units, observation posts, and targets on a common grid system. This requirement extends to establishing the common grid for all division elements that require survey control, i.e., mortar platoons, air defense systems, and military intelligence target acquisition systems.

a. The common grid permits the field artillery to accomplish the following:

--Massing of Fires. Accurate survey permits rapid and economical massing of fires. Massing of fires without survey requires an observed adjustment of all units on the target or prior registration of all units on a common registration point.

--Delivery of Surprise Observed Fire. The element of surprise is lost when all batteries are required to adjust on a target. Complete surprise cannot be obtained without survey.

--Delivery of Effective Unobserved Fires. Consistently effective observed fires can be accomplished only if the target has been previously fired upon and replot data computed.

--Transfer of Target Data Between Units. The transfer of target data between units is possible only when units are located relative to each other and to the target.

b. In the past, the ability to place all elements on a common grid has existed only when the tempo of battle slows considerably. The slow speed of survey operations caused frequent use of hasty survey techniques and emphasis on providing only common directional control. The use of hasty techniques results in a serious degradation of the effectiveness of the FA system.

2-6 TRENDS. Serious efforts have been made over the years to improve the timeliness of survey operations and to improve the accuracy of hasty survey equipment and techniques.

a. Electronic distance measuring equipment was initially fielded in 1970 for fourth-order survey parties. Its use was extended to fifth-order parties in 1978 and a requirement for fifth-generation equipment is pending approval at HQ TRADOC. This equipment increased the speed of survey operations by a factor of two.

b. Research and development on the PADS was initiated in 1971. The system successfully completed engineering development and was type classified in 1979. The first unit, 82d Airborne Division Artillery, was equipped in March 1982. The PADS linear rate of survey (6.5 km per hour) is a threefold increase over distance measuring equipment (2 km per hour).

c. The rapid advance of technology during the 60's - 70's spawned many opportunities for advancement in positioning-navigation. Both the Army/USMC PLRS and the Joint Service GPS systems, which can provide near-real time positioning data, were initiated during this timeframe. The late 1970's saw the development of the first on-board FA fire control system for the MLRS and initiation of a similar system for self-propelled howitzers in the early 80's. The USMC completed development of a small, lightweight azimuth gyro for observer use during this timeframe.

d. In summary, technology now offers the capability for the field artillery to achieve real-time position and orientation data. The successful use of these systems demands a close examination of FA requirements and systems capabilities in order to establish a valid course of action for the future.

CHAPTER 3

SYSTEMS DESCRIPTIONS

3-1. SCOPE. This chapter describes the Division 86 Force Structure survey systems, on-board fire control/positioning systems and additional systems postulated for fielding in the FY 87 or later timeframe. Systems organic to FA sections are presented first, followed by the equipment/procedures utilized by survey sections and a discussion of external positioning/navigation system. The discussion includes a general description of the system, its accuracy and response time.

3-2. ORGANIC EQUIPMENT. This category includes topographic maps, laser range-finding equipment, magnetic means of orienting FA systems and on-board fire control/positioning systems.

a. Topographic Map. A topographic map portrays terrain and landforms in measurable form, as well as the horizontal positions of the features represented. The vertical positions, or relief, are normally represented by contours. Maps are considered in this analysis because they are available to every survey user and may be used as a hasty technique to determine position and orientation data in the absence of better data. The scale of the map used for survey purposes is normally 1:50,000.

(1) Accuracy of Construction.

(a) Horizontal accuracy. Ninety (90) percent of all well defined features, with the exception of those unavoidably displaced by exaggerated symbolization, are located within two one-hundredths of an inch (.02 in), at publication scale, of their geographic location, as referred to the map projection. (Approximately 26 meters on a 1:50,000 scale map.)

(b) Vertical Accuracy. Ninety (90) percent of all contours and elevations interpolated from contours are accurate within one-half of the basic contour interval. Contour intervals are usually 5 meters or 20 feet on 1:50,000 scale maps.

(2) Map Reading Accuracy. The accuracy of a position location and/or orientation determined from a topographic map is limited by the skill of the map reader and construction standards of the map (para (1) above). Data on map reading accuracy is limited to various training effectiveness analysis and HELBAT exercises conducted over the past ten years on the forward observer's ability to locate his position by map reading. Since standard data collection/analysis methods were not used throughout the reports a statistical measure could not be obtained. Horizontal position errors ranging from 93 meters to 340 meters were reported. An accurancy of 150 meters CEP was used in this analysis. A vertical position error of 10 meters PE was assumed. An accuracy for orientation determined from the map could not be determined.

b. Magnetic Compass, M2. The compass is a multiple purpose instrument. It can be used as a clinometer and to measure angle of site in addition to the azimuth measurement capability discussed in this study. The azimuth scale is marked in mils and can be rotated approximately 1800 mils to establish the grid-magnetic angle. The compass is equipped with a circular level, front and rear leaf sights, and a mirror inside the cover for sighting and reading the angles. An azimuth is determined by setting the grid magnetic angle on the azimuth scale; sighting on the azimuth mark while leveling the circular bubble; and, reading the azimuth from the magnetic needle by means of the mirror, which is positioned over the scale during the measurement.

(1) Accuracy. An Army standard has not been established because of the wide variations in magnetic fields and local attractions throughout the world. The most current source of information is the HELBAT (Human Engineering Laboratory Artillery Battalion Test) series of field experiments conducted at Fort Hood and Fort Sill. The study used an error of 54.15 mils (PE) based on the use of the compass by forward observers in HELBAT II, conducted at Fort Hood in 1972.

(2) Response time. An Army standard measurement of an azimuth with the magnetic compass has not been established. A response time of two minutes was established based on military judgment.

c. Hand-Held Laser Rangefinder (HHLR), AN/GVS-5. The HHLR is a lightweight, hand-held, battery-operated device for use by observers to determine range to targets/reference points. Range is determined by measuring the time of flight of the laser pulse to and from the aimpoint and converting this time to distance. The range is displayed in the reticle pattern. The HHLR weighs approximately 5 pounds and has a 7 x 50 monocular optical sighting system.

(1) Accuracy. The HHLR measures ranges from 200 to 9990 meters. Range is displayed to the nearest 10 meters. An accuracy of 3.42% of range 1 standard deviation, was extracted from the HHLR Operational Test II Report, December 1976. More recent USAFAS field testing and experience indicate that 1.00% of range, 1 standard deviation, is a more realistic estimate. Since the discrepancy is unresolved, both estimates were considered in the analysis. HHLR-1 and HHLR-2 denote the "accurate" and "inaccurate" modes used herein. The accuracies of the HHLR-1 and HHLR-2 for observer to target ranges considered in this analysis may be expressed in meters probable error as follows:

HHLR	OT Range (km)	PE(m)
HHLR-1	2	13.5
	3	20.2
HHLR-2	2	46.1
	3	69.2

(2) Response time. The HHLR measures the range in one second.

d. Ground Laser Locator Designator (GLLD), AN/TVQ-2. The GLLD is a man-portable, tripod-mounted, laser device that provides the Fire Support Team (FIST) headquarters with the capability to: provide precision designation for laser guided munitions; determine range to targets/reference points in the same manner as the HHLR; and, when accurately oriented, determine azimuth and elevation angle data that, when coupled with distance data, can be used to significantly improve target location or self-location accuracies. The GLLD can be operated from self-contained battery or vehicle power.

(1) Accuracy. The GLLD measures ranges from 250 to 9990 meters. Range is displayed to the nearest meter. The accuracy of the rangefinder and tripod are:

(a) Range - 0.22% of range PE. (Source: GLLD DT/OT Report, Arctic Test Center, 1979).

(b) Angular error - 2 mils, PE.

(c) Elevation angular error - 5 mils, PE.

(2) Response time. The GLLD measures and displays range, azimuth, and elevation data in one second.

e. Aiming Circle, M2A2. The Aiming Circle, is a small, lightweight, tripod-mounted instrument capable of measuring angles, determining magnetic or grid azimuth and reciprocal laying of howitzers and launchers. The aiming circle is issued to all howitzer/missile batteries for use in laying the battery and to other sections, i.e., Mortar Locating Radar, for radar orientation.

(1) Accuracy. System accuracy is expressed in two ways: first, an accuracy of a grid azimuth determined through use of the magnetic needle; and, second, the accuracy associated with transfer of an azimuth from a surveyed orienting line to the sighting equipment on board the FA system, i.e., howitzer/radar sight.

(a) The accuracy of the magnetic needle is dependent upon variations and deviations of the local declination and man-made anomalies. An accuracy of 6 mils (PE) was assumed for this study, based on a field experiment at Fort Sill.

(b) The aiming circle is the commonly used method for transferring the orienting azimuth from the surveyed orienting line or the circle's magnetic needle to the sighting system. Regardless of the method used, additional error is introduced by plumbing and leveling errors, design limitations and human error. A transfer error of 1.2 mils (PE) was used on this study based on the following rationale.

(c) In August 1979, Human Engineering Laboratory (HEL) conducted a HELBAT 7 subtest, <u>Howitzer Emplacement and Fire Control Accuracy Study</u>, to explore the operational capability of test bed howitzer fire control systems. The performance of on-board fire control systems was compared against a control howitzer, a standard howitzer laid by the aiming circle method. The test report, Technical Memorandum 15-80, August 1980, contains the following information on laying error.

Table 3-1. Control Lay Error Data (Absolute)

Lay	Crew 1	Crew 2	Crew 3	All
$\bar{X}$	2.46	3.18	18.35	9.10
SD	1.51	2.27	55.72	35.55
N	(11)	(8)	(13)	(32)

*Extracted from Table 6D, Tech Memo 15-80, HEL, August, 80

The above errors were determined by comparing the measured azimuth of lay against a second order geodetic azimuth. Since these errors represent a total error of lay it was necessary to determine typical accuracy of the orienting line to determine the transfer error. An error of 0.4 mil (PE) was obtained from data provided by the

HELBAT I field experiment at Fort Hood in 1969. This experiment established the base line performance of a field artillery cannon battalion, to include the survey section. The transfer is then computed as follows:

(1) A standard deviation was computed from the data in table 3-1. The data from crew 3 was considered an outlier and was deleted. The standard deviation is 1.83 mils, which converts to a probable error of 1.23 mils.

(2) The orienting line error (0.4 mils PE) stripped from the total error (1.23 mils PE) results in a net transfer error of 1.16 mils PE.

(3) The above results were compared with data provided by a BDM Services Corporation Study, Accuracy Analysis of Artillery Cannon Systems, Volume 3, 28 February 1975. The study provided a transfer error of 1.0 mils PE. The HELBAT data was used since it is more current and is based on field performance.

(4) Response Time. The time required to orient (lay) a weapons system is based upon the Soldier's Manual tasks for laying a howitzer battery, Tasks 061-266-4145/4146, FM 6-13B4, Cannon Crewman. The response time for day operations is five minutes; the time required for night operations is eight minutes.

f. Multiple Launch Rocket System (MLRS) Stabilized Reference Platform/ Position Determining System (SRP/PDS), The SRP/PDS is composed of an electrically driven north seeking gyro compass and a position determining system. The SRP provides direction, elevation, and cant angle to the fire control system. The PDS provides position location data to the fire control system based upon an initial initialization/calibration and position updates every eight kilometers. While the SRP/PDS eliminates the requirement to perform position area survey it imposes requirements for initialization, calibration and update points in each MLRS platoon area of operations. One PADS per battery has been authorized to perform this survey function. MLRS IOC is FY 83.

(1) Accuracy.

(a) Orientation - 0.67 mil PE.

(b) Position

Horizontal - 0.2 - 0.4% of distance traveled. A 15 meter CEP was assumed for this study.

Vertical - ± 5 meters. One standard deviation.

g. FIST Vehicle (FISTV) North Seeking Gyro (NSG) is a subsystem in the FISTV Targeting Station. The NSG, which is aligned with the Laser Designator/Range Finder Module of the GLLD, also in the targeting station, establishes grid north from which the azimuth angle is determined and the vertical reference from which vertical angles are measured. The Targeting Station transmits the azimuth and the range to the target to the Digital Message Device at the Communications Station. The FISTV will utilize the PLRS system, when fielded, for position data. FISTV IOC is FY 85.

(1) Accuracy. A specific accuracy for the NSG was not specified in the requirements document, instead, the Targeting Station is required to locate a target within 40 meters (CEP) at three kilometers range. This requirement is independent

of vehicle location errors, which are expected to be less than 50 meter (CEP) with PLRS. An accuracy of 1.35 PE of range was assumed for this study based on emerging results of test data in the FISTV development program.

(2) Response Time. Approximately five minutes are required for initial initialization and run-up of the gyro. A realignment, requiring two minutes, is required every two hours. The response time is immediate on any given mission, once initialized.

h. M109A3/M1102A2 Automatic Gun Positioning System (AGPS). The Army has been investigating on-board positioning and fire control systems for self-propelled howitzers for a number of years. A requirement for the AGPS is included in the M109A3 HELP PIP and in the M110A2 Mid Life PIP, and prototype systems are undergoing evaluation. The systems operate in a manner similar to the MLRS SRP/PDS with the exception that the present programs do not include computation of fire commands and the howitzer crew must slew/elevate/depress the tube with current controls. The systems also differ in that the developer may incorporate a PLRS or GPS User Unit to provide the initialization and update data required. Survey support will be required to establish the necessary control points for redundancy purposes. IOC for the AGPS on the M109A3 is FY 87; M110A2 FY 88 or later.

(1) Accuracy.

(a) Orientation - 0.67 mils PE.

(1) Horizontal - 0.25% of distance traveled, one sigma. An accuracy of 15 M CEP was assumed for this study.

(2) Response time. Fifteen minutes are required for initialization of the gyro; thereafter a realignment, requiring two minutes, is required for every two hours. After initialization and update, when required, the system will instantaneously provide gun tube azimuth and elevation.

i. Azimuth Measuring Device (AMD). The AMD is descsribed in the <u>Draft Required Operational Capability for an AMD</u>, USAFAS. It is intended to fill a requirement for a small, lightweight, low cost azimuth measuring device which can provide an orienting azimuth for selected Army systems, in static position, under adverse weather conditions, during day and night, in all areas of operation, in a responsive manner. The required accuracy/response times are as follows:

ACCURACY (PE)	TIME (minutes)
0.34 mil	20
0.67 mil	4
1.35 mil	2

3-3. SURVEY SECTION EQUIPMENT/PERSONNEL. This paragraph provides an overview of Division 86 survey equipment and personnel authorizations, followed by a description of system components.

a. General. The survey system contains a mix of automated and manual survey parties and planning/coordination elements at FA battery/battalion and division artillery level. Automated parties are equipped with the PADS IOC CY 82, and the manual parties utilize commercial angle and distance measuring equipment, supplemented by the Army developed Surveying Instrument Azimuth Gyro, Lightweight (SIAGL). Survey parties referred to as PADS and Conventional (Conv), are authorized as shown at Table 3-2.

Table 3-2. FA Division 86 survey party structure.

TYPE UNIT	PADS	CONV
ACR Battery	1	0
Missile Battery	1	1
Cannon Battalion		
3 x 6	3	0
3 x 8	3	0
Cannon/MLRS Battalion	3	0
MLRS Battalion	3	0
HHB Division Artillery	3	0
TAB Division Artillery	1	2

The number of personnel required to operate a heavy division slice survey system are shown at Table 3-3. The system contains 25 two-man PADS parties, two 6-man parties, and a 3-man planning/coordination element for each headquarters.

Table 3-3. Survey system personnel requirements

TYPE UNIT	PADS	CONV	COORD	NO. PERSONNEL
DS BN, 3 x 8 (3)	18	0	9	27
Cannon/MLRS BN	6	0	3	9
HHB, DIV ARTY	6	0	3	9
TAB DIV ARTY	2	12	3	17
NON-DIV Cannon Bn (3)				
(3 x 6, 8-Inch)	18	0	9	27
TOTALS	50	12	27	89

The quantities of major items of equipment required to operate a heavy division slice survey system are shown at table 3-4.

Table 3-4. Division 86 survey system equipment requirements

MAJOR ITEM	NO IN PARTY CONV	NO IN PARTY PADS	COORD ELEMENTS	TOTAL DIV SLICE
PADS, USQ-70		1		25
Radio Set: GRC-160	2			4
Radio Set: VRC-46		1	9	34
SIAGL	1			2
Survey Electronic Distance Measuring Equipment (SEDME)	1			2
Theodolite	1	1		27
High Mobility Multi-purpose Wheeled Vehicle (HMMWV)	2	1	9	38

b. Position and Azimuth Determining System (PADS). PADS is a self-contained surveying system, capable of rapidly determining accurate position, elevation, and azimuth data when used in either ground or air transportable survey operations. The system is normally installed in a M151, 1/4-Ton truck, however, it may be transferred to an OH-58A light observation helicopter, or, the M151 may be transported by CH-47 cargo helicopter. PADS is operated by a two-man crew. The PADS mission profile is defined as five hours of operation or a total distance traveled of 55 km. Approximately 30 minutes is required for initial initialization and for re-initialization after 5 hours operation, traveling 55 km, or shutdown. The normal mode of operation requires a zero velocity update every ten minutes. The PADS was fielded in 198^, however, the active duty force will not be completely equipped until 1987, or later, depending upon procurement and fielding of Division 86 organization.

(1) Accuracy.

(a) PADS has consistently performed better than ROC requirement. The table below compares the ROC requirement versus the First Article Test results used in this study. (ten minute updates)

DATA	REQUIRED	FAT
Horizontal Position	20 M (CEP)	5.73 M (CEP)
Verticle Position	10 M (PE)	1.88 M (PE)
Azimuth (grid direction)	0.67 mil (PE)	0.4 mil (PE)

(b) USAFAS has conducted informal evaluations to determine if PADS accuracies can be improved by reducing the time period between zero velocity updates. The evaluation, conducted in the September, 1979 to April 1980 time frame, was discussed in the July-August 1980 issue of THE FIELD ARTILLERY JOURNAL. The data presented indicates that position data can be improved significantly with the use of a three-minute update. This evaluation was the basis for determining that the shorter update period would be used when surveying the sound base. The following PADS accuracies for three-minute update were used in this analysis. Additional formal testing is required to establish PADS performance at these shorter update periods.

1 Horizontal - 3 M (CEP)

2 Vertical - 1 M (PE)

3 Azimuth - 0.4 mil (PE) (Not changed because the data presented in the JOURNAL is inconsistent).

(2) Response Time. The following times are typical of PADS operation, when mounted in the M151 truck, the primary method of operation. The M151 will be replaced by the HMMWV in the 1983 time frame.

(a) Linear rate of survey - 6.5 km per hour (Extracted from OT IIA Test Report - defined as the total straight line distance between survey stations established by PADS, in the order visited, divided by the total time required for the survey).

(b) Mark coordinates of station five minutes

(c) Establish orienting line - five minutes (two position method)

(d) Establish azimuth on offset point - 10 minutes

c. Conventional Survey Party Operations. Conventional survey parties were retained on FA TOE to supplement PADS in the extension of survey control and to perform target area survey operations, where applicable. Survey parties in battalion and battery level units conduct fifth order survey operations while division artillery and the target acquisition battery conduct fourth-order operations. The primary difference in these operations is the type of theodolite used. The more accurate T-2, 0.002 mil theodolite is used in fourth-order work and the T-16, 0.2 mil instrument is used in fifth-order operations.

(1) Accuracy

(a) Distance - one meter in 3000 meters (fourth-order) or
one meter in 1000 meters (fifth-order)

(b) Angles - 0.03 mil (PE) per station angle (fourth-order)
0.09 mil (PE) per station angle (fifth-order)

(c) Composite- The following data was extracted from the Final Letter Report, Field Artillery Survey Test, USAFAB, 19 January 1979. The FDTE was conducted to gather data regarding the conduct of FA survey using fifth order techniques and to gather data that could be used to compare test results from the PADS OT IIa.

Horizontal - 2.99 M CEP
Vertical - 1.51 M PE
Azimuth - 0.39 miles PE

An azimuth accuracy of 0.12 mils PE was derived for fourth-order survey parties based on the data at paragraph c(1)(b) above.

(2) Response Time. The planning factors for the two commonly used methods of survey are extracted from paragraph 9-5, FM 6-2.

METHOD	BEST SUITED FOR	RATE OF EXTENSION
Traverse	Gently Rolling Terrain Flat terrain Along roads or trails	2,000 meters per hour with SEDME (Primary) 1,000 meters per hour with tape (backup)
Triangulation	Difficult Terrain Crossing obstacles	30 minutes per station plus reconnaissance and travel time.

d. SIAGL. The SIAGL is a portable north-seeking gyroscope capable of determining true north with high accuracy without the assistance of celestial or landmark sightings. The SIAGL consists of a gyroscopic reference unit with an integral theodolite and tripod assembly; electronic control unit; transit case, which houses the reference unit; and ancillary equipment. The complete SIAGL, less the wind shelter, is contained in a transport case. The SIAGL, as well as other gyroscopes, must be protected from wind and vibration, to obtain accurate readings.

(1) Accuracy. The accuracy of the SIAGL is dependent upon the latitude of the site where used. Accuracies expected at latitudes from o° to 75°, extracted from the DT III Test Report, are listed in table 3-1.

Table 3-5. SIAGL azimuth accuracy table

LATITUDE (Degrees)	ACCURACY (Mils-PE)	LATITUDE (Degrees)	ACCURACY (Mils-PE)	LATITUDE (Degrees)	ACCURACY (Mils-PE)
0	0.101	30	0.117	55	0.177
5	0.102	35	0.123	60	0.202
10	0.103	40	0.132	65	0.239
15	0.105	45	0.143	70	0.296
20	0.108	50	0.157	75	0.391
25	0.112				

(2) Response Time. The instrument is capable of determining true north within 45 minutes (includes set-up and measurement time). This time was extracted from Soldier's Manual Task 061-302-1019, FM 6-82C/I/2.

e. Astronomic Observation. Field artillery surveyors are trained to conduct astronomic observations of the sun and stars for the purpose of obtaining a true direction, which is mathematically converted to grid direction. The standard angle measuring theodolite, DA computation forms and the hand-held calculator or logarithmic tables are used. Time accurate to 1 second is required when using the hour-angle method of observation compared to time accurate to five minutes with the altitude method of observation. Either method is limited by weather conditions.

(1) Accuracy. The accuracy obtained is dependent upon the type of theodolite used by the survey party. The following accuracy standards are extracted from paragraphs D-4, Appendix D, FM 6-2.

(a) Fourth order - 0.06 mil (PE)

(b) Fifth order - 0.12 mil

(2) Response time. The time standard for astronomic observations was extracted from FM 6-82C/1/2 as follows:

TASK	TASK NUMBER	TIME STANDARD (minutes)
Set Up Instrument	061-302-1005	5
Observe Sun/Stars	061-302-1021/2	15
Computations	061-302-1034/5	15
	TOTAL TIME	35

3-4. POSITION/NAVIGATION (POS/NAV) SYSTEMS. Three POS/NAV systems are under development by DOD agencies. The Position Location Reporting System (PLRS), under development by the Army and USMC, the PLRS/JTIDS Hybrid System (PJH), a PLRS derivative system under Army development, and the Global Positioning System (GPS), a joint services development, are described below.

a. PLRS is a time division multiple access (TDMA) UHF network employing a master station to provide computations and net control, an alternate master station, which acts as a hot-spare, auxiliary user units to optimize relay over the horizon, and up to 720 user units - 370 active at any one time. PLRS will be capable of providing position location, navigation, identification of users, and limited digital data message exchange. The system is limited in that it does not provide an azimuth of sufficient accuracy to orient systems. The navigation program provides an azimuth to the nearest degree. PLRS completed OT II in December, 1981.

(1) Accuracy-

(a) Horizontal - The JSOR requirement for artillery positioning is 20-30 meters CEP. The OTEA OT II Test Report states that a typical accuracy of 15 meters was achieved. PLRS position accuracies do not, however, follow a normal distribution. Position accuracy is very dependent upon the number of relays between the user and the master station and the mathematical strength of the triangles used in the calculations. These factors can result in a large position error. A CEP of 30 meters was used in this study as a more realistic estimate of consistent position accuracies.

(b) Vertical - The JSOR requirement is ±3% of the altimeter reading. The OT II Report did not address vertical error. The DT report indicates quite a variance in altitude errors. A 10 meter PE was assumed in this study.

(2) Response time - The system is required to provide a recomputed position for each user at least every 32 seconds. The time required for a user to obtain his position will vary from 8 seconds to 3 minutes (estimate), based on system load.

(3) User Units - User units, vehicle mounted, will be issued to the following users:

(a) Division Artillery and FA Cannon Brigade - Commander and TOC

(b) FA Cannon battalions -

Commander
Operations/Fire Direction Section
S4
Howitzer Battery Commanders
Platoon/Battery Fire Direction Centers
FIST HQ (Mech Inf, Armor, Armor Cav only)
MLRS Platoon Leader

(c) Target Acquisition Systems - FIREFINDER Radar, Ground Surveillance Radar, and RPV Platoon.

b. Position Location Reporting System (PLRS)/Joint Tactical Information Distribution System (JTIDS) Hybrid (PJH). The PJH System combines the characteristics of PLRS, described above, and JTIDS, also a time-ordered spread spectrum system, PJH is primarily intended for deployment within the division area to meet data communications, identification, and/or position location requirements of division units and echelons above division units which habitually operate in the division area, such as Corps Field Artillery Battalions. The primary difference in employment of the system, for FA users, is that the Enhanced PLRS User Unit (EPUU) replaces FM radios now utilized for FM digital communications. FA users include those listed in paragraph c, above, plus all platoon forward observers in Fire Support Teams. This change is significant in that the PJH can provide horizontal and vertical position data for dismounted observers vice the inability to obtain this data from the PLRS because dismounted observers cannot carry the PLRS User Unit, in addition to their current communications equipment. The accuracy and response time for PJH are the same as described for PLRS.

c. Global Positioning System (GPS). The GPS is a space-based POS/NAV system that will provide three-dimensional position data and navigation information. The system consists of a space segment of 18 satellites, a control and update segment, and user units (UU), which are lightweight receiver/ computer units designed for manpack/vehicular or aircraft use. The FA has stated BOIP requirements for UU's in Pershing and Lance units and has addressed the use of UUs, in conjunction with appropriate azimuth devices, as a replacement for some PADS units in the GPS Operational and Organizational Plan. The GPS DT/OT II is scheduled for February-November 1983.

(1) Accuracy - (extracted from requirements document)

(a) Horizontal - 8.5 meters CEP

(b) Vertical - 10 meters PE

(2) Response Time

(a) Reaction Time (REAC) - 10.5 minutes. The time from user equipment turn-on until the first full accuracy data output is derived from four satellites.

(b) Time to First Fix (TTFF) - 5.5 minutes. The elapsed time from the initial demand on a set that has been turned on for a minimum of seven (7) minutes to the subsequent display of data with the specified accuracies.

CHAPTER 4

ANALYSIS OF ALTERNATIVES

4-1. PURPOSE. To select survey subsystems which satisfy FA systems position and orientation requirements.

4-2. METHODOLOGY. The analysis is conducted in four steps as follows:

a. Identify the base case survey system and alternatives. Summarize the performance characteristics, described at chapter 3, for each.

b. Summarize the FA systems requirements, described at chapter 2, for each user.

c. Select the survey subsystems from the base case for each user and provide rationale for the selection.

d. Repeat step c for alternative systems.

4-3. BASE CASE/ALTERNATIVE SYSTEMS. The 1986 base case and alternative systems, and associated performance characteristics are listed at table 4-1. The basis for selection of alternatives is an IOC date of 1987 or later.

4-4. FA SYSTEM REQUIREMENTS. Orientation, position accuracy, and response time requirements, discussed at chapter 2, are summarized at table 4-2.

4-5. SURVEY SUBSYSTEM SELECTION. An initial analysis was conducted to select the survey subsystems that can provide orientation and position data for each user. The selection was accomplished in two steps. Initially, all subsystems that could satisfy any portion of the user's requirement was identified. These systems were further analyzed to determine those that could satisfy all requirements and/or the operational feasibility of the subsystem actually performing the task. The resultant subsystems combinations, table 4-3, were then identified for further analysis to determine the impact of orientations or positioning errors on the total FA system delivery error. The analysis for each user is discussed in subsequent paragraphs.

Table 4-1. 1986 Base case survey system and alternatives

SURVEY SYSTEM	ACCURACY HOZ (CEP-M)	VERT (PE M)	ORIEN (PE M)	RESPNS TIME (min)	REMARKS
1. 1986 Base Case System					
a. Map	150	10	-		
b. Compass	-	-	54.15	2	
c. Aiming Circle M2A2	-	-	6.0	5/8	Day/night
d. MLRS SRP/PDS	15	3.37	0.67	0	Horiz.-0.2-0.4% of distance traveled
e. FISTV NSG	SEE	PLRS	8.0	0	
f. CONV SVR PTY	2.99	1.51	0.39	-	2KM Per Hr-Traverse 30 Min Per Sta-Triangulation
g. SIAGL	-	-	0.123	45	Accuracy dependent upon lat. value cited is 35°
h. Astronomic Observation	-	-	0.06	35	Considered a part of survey party operations
i. PADS	5.73	1.88	0.4	-	6.5KM Per Hr
j. PLRS	30	10.0	-	1	
2. 1987-88 Alternatives					
a. AGPS	15	3.37	0.67	0	
b. AMD	-	-	0.34 .67 1.35	20 4 2	
c. PJH	SEE	PLRS			Same as PLRS
d. GPS	85	10.0	-	5.5	Assumes user equipment has been turned on for 7 minutes.

Table 4-2. Orientation, position accuracy and response time requirements

SYSTEM	Orientation (PE) (MILS)	Hor Position (CEP) (Meters)	Vert Position (PE) (Meters)	Response Time (Minutes)
Ground Observers w/o GLLD	10.0	87.5	20	2.0
Ground Observers w/GLLD	10.0	87.5	20	5.0
FISTV	10.0	87.5	20	3.0
Howitzer Battery-SP	0.3	17.5	10	0.5
Howitzer Battery-Towed	0.3	17.5	10	4.0
MLRS	1.0	35.0	10	0.0
LANCE	0.3	35.0	10	0.0
RPV	0.50	21.0	10	30.0
MTLR	3.0	43.75	30	30.0
MLR	0.3	10.0	10	15.0
WLR	0.15	10.0	3	30.0
MDS	9.0	114.0	10	5.0
SOUND BASE	NA	0.9		NA

Table 4-3. Survey subsystem alternatives for survey users

CATEGORY	BASE CASE SUBSYSTEMS												ALTERNATIVES		
	HASTY						DELIBERATE						DELIBERATE		
SURVEY USER	MAP	COM-PASS	HHLR	GLLD	AC	PLRS	SRP/PDS	FISTV NSG	SURV PTY	SIA-GL	PADS	PJH	AMD	AGPS	GPS
1. GD OBS w/o GLLD	*P-0	-0	P-									P-	-0		
2. GD OBS w/GLLD	P-0	-0	P-	P-								P-	-0		
3. FISTV	P-0	-0		P-		P-		-0				P-			P-
4. S/F OBSN SEC	P-	-0	P-			P-					P-0	P-	-0		P-
5. SD RANGING	P-				P-				P-		P-	P-			P-
6. RPV	P-				P-	P-			P-0	-0	P-0	P-	-0		P-
7. MTLR	P-				-0	P-			P-0	-0	P-0	P-	-0		P-
8. MLR	P-				-0	P-					P-0	P-	-0		P-
9. WLR	P-				-0	P-			P-0	-0	P-0	P-	-0		P-
10. MDS	P-				-P	P-						P-	-0		P-
11. HOW BTRY-SP	P-0				-0	P-					P-0	P-		P-0	P-
12. HOW BTRY-TOWED	P-0				-0	P-					P-0	P-	-0		
13. MLRS						P-	P-0				P-	P-			P-
14. LANCE									P-0	-0	P-0				P-

*P - Position

0 - Orientation

4-6. Ground Observers Without GLLD. This category of users includes all platoon forward observer teams (three teams in each infantry FIST), the infantry FIST HQ in the airborne division and all FIST HQ in the air assault division. All users are equipped with the map, compass and HHLR. All FIST elements operate in a dismounted mode; the one vehicle authorized each infantry FIST is deployed with the supported company trains element where it is utilized for administrative and logistical purposes. The observers move frequently in conjunction with the maneuver elements they support.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	
Compass	PADS
HHLR	SIAGL
PLRS	

b. All deliberate systems were eliminated from further consideration because of their inability to respond to frequent observer moves and the low survivability of these systems when employed in close proximity to the main battle area. The PLRS was eliminated from consideration because none of the elements can transport the User Unit (UU), weight 23.5 pounds with batteries, in addition to their present equipment. An operational assessment of the UU weight problem, conducted by USAFAS in April 1981, resulted in the deletion of the UU from all dismounted FIST elements and the mechanized infantry platoon forward observer teams.

c. The elimination of the above systems limits availability of position and orientation data to that provided by hasty methods. The following methods of self-location were selected for further analysis:

HASTY

Map
Compass
HHLR

d. Two alternative systems, the PJH and AMD, apply to all ground observers.

(1) The PJH system differs significantly from the PLRS in that it is both a position locating system and the primary digital communications system. The PLRS User Unit becomes the Enhanced PLRS User Unit (EPUU) and replaces FM radios currently used on the fire direction nets. This change makes it operationally feasible for all ground observers to obtain position data from the PJH while also improving the digital communications system. The PJH Operational and Organizational Plan presently includes all FIST observers. The accuracy of position information obtained from the PJH system is the same as the PLRS.

(2) Employment of the AMD by ground observers offers a significant improvement in orientation accuracy. The system capability, as described in the USAFAS Draft Proposed Required Operational Capability (DPROC), in terms of accuracy and response time is 1.35 mils PE in 2 minutes for observer use. Two additional levels of accuracy and response time, 0.67 mil PE in 4 minutes, and 0.34 mil PE in 20 minutes, described in the DPROC, are applicable to other systems. While there is

no doubt that use of the AMD for observers should be considered because of the improvement in accuracy of orientation, there is some doubt about the ability of dismounted observers to transport (backpack) the equipment. The AMD weighs approximately 5 pounds, however, it must be mounted on a tripod for leveling and stabilization. A review of the state-of-the-art indicates that the maximum weight of the tripod would be about 8 pounds, or a total weight of approximately 13 pounds. Previous USAFAS assessments of observer weight problems have concluded that observer parties are already overloaded and no additional equipment can be carried. The AMD is retained in the analysis to determine its operational impact on observer (system) effectiveness.

e. The Global Positioning System (GPS) is not considered suitable for ground observers because it does not replace any communications equipment and the additional weight (approximately 15 pounds) cannot be transported by the observer team.

4-7. Ground Observers with GLLD. This category of user includes the infantry FIST HQ and separate observation/lasing teams in the infantry division. These users are also equipped with the map, compass, and HHLR. The weight of the GLLD system limits its employment with the infantry FIST HQ to situations where time is available to backpack the system from the FIST HQ vehicle, normally positioned in defilade some distance from the FIST HQ, which is collocated with the supported company headquarters.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	
Compass	PADS
HHLR	SIAGL
GLLD	
PLRS	

b. All systems except the map, compass, HHLR, and GLLD were eliminated from consideration on the same basis of the rationale used in paragraph 4-6, Ground Observers without GLLD. Position and orientation data is only available from hasty methods. These methods are the same as those discussed in the preceeding paragraph with the exception that the GLLD may be utilized for self-location. The following methods of self-location were selected for further analysis:

<u>HASTY</u>

Map
Compass
HHLR
GLLD

c. The alternative systems discussed in the previous paragraph 4-6e, PJH and AMD, also apply to the ground observer with GLLD. The transportability of the AMD is not a problem for two reasons. First, the traversing unit module of the GLLD has been designed to accommodate mounting of an AMD device and, second, the additional five pounds of weight does not affect the operational concept for employment of the GLLD discussed above. The AMD DPROC presently includes GLLD-equipped observer teams in the basis of issue plan. The PJH will be employed as described earlier for ground observers without the GLLD. The GPS is eliminated for the same reasons discussed at paragraph 4-6e.

4-8. FISTV. The FISTV, XM 981, will replace the Armored Personnel Carrier, M113A2, currently authorized for mechanized infantry, armor, and armored cavalry FIST's. Vehicle systems include a north seeking gyro (NSG), which is aligned with the GLLD's Laser Designator Rangefinder Module in the targeting station. Other section equipment includes the map, compass, HHLR and the PLRS User Unit. The vehicle location, determined by PLRS, is input to the targeting station computer. The computer determines target location based on this input as well as the range, azimuth, and vertical angle to the target which is input from the NSG and GLLD.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	NSG
Compass	PADS
HHLR	
PLRS	
GLLD	

b. The FISTV operational and organization plan envisions the use of the NSG and PLRS to satisfy all orientation and positioning requirements and the system design indicates that the QSTAG survey accuracy requirements will be satisfied by these equipments. If the NSG or PLRS is not operational, the FIST's orientation and positioning requirements will be satisfied by one of the hasty methods utilized for other observers.

c. The following systems were retained for further analysis:

HASTY	DELIBERATE
Map	NSG
Compass	PJH
HHLR	GPS
GLLD	
PLRS	

d. The PJH is the alternative system applicable to the GLLD. The AMD could be used with the GLLD, when dismounted, however, this type usage is forecast as ocurring only 10 percent of the time and it does not appear cost-effective to add the AMD for this limited usage. The PJH replaces the PLRS system with no change in the capability to provide position data. GPS can also be used to provide position data, however it does not provide a digital communications capability and will only be used if PLRS/PJH is not fielded.

4-9. Sound/Flash Observation Section. There are two four-man observation sections in each of the two sound/flash ranging platoons in the target acquisition battery. The primary mission of the section is to cue (activate) the sound base when the firing of hostile weapons is heard. If the position selected to accomplish this function also permits observation of the battle zone the section may conduct fire missions in a manner similar to FIST observers. Initially the section self-locates utilizing hasty methods and survey control is established as time permits. A sound base is not normally established unless the tactical situation permits operation for three or four hours, therefore the observation sections will be in position for longer periods of time than the FIST observers, discussed earlier. Section equipment includes the map, compass, HHLR and the tripod-mounted Battery Commander's Periscope, a long-range observation instrument. The section vehicle is positioned in defilade near the observation post.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
Compass	PADS
HHLR	SIAGL

b. Sound/Flash Observation Sections differ from other ground observers in three respects. First, the location of the sound ranging microphones will determine the general location of the observation posts (OP). This restriction will limit the usefulness of the posts for the secondary mission in that the sound base cannot move as rapidly as the maneuver forces. Second, the OPs are located 750-1000 meters in front of the sound base and it is relatively easy to extend control to the OPs in conjunction with survey of the base and, third, the section vehicle is positioned in close proximity to the OP. The vehicle is available for storage of equipment and the section equipment is not limited to that which can be transported on the individual. Thus, the PLRS User Unit can be added to section equipment as a means of providing hasty position data prior to completion of the deliberate survey. The only means of initial orientation is the compass. Hasty resection methods can also be used to obtain position data. The sound ranging central computer has been programmed to perform the calculations for hasty resection.

If time permits, survey of the OP by deliberate means will be accomplished by the same system that surveys the sound base, discussed in the subsequent paragraph. The SIAGL is eliminated from further consideration because it lacks necessary mobility and requires too much time to obtain an azimuth.

c. The following systems were retained for further analysis:

HASTY	DELIBERATE
Map	PADS
Compass	Survey Party
HHLR	
PLRS	

d. The PJH EPUU will replace the FM radio used by the sound/flash observers in the same manner as discussed for other observers because the section must communicate with the TACFIRE system by digital means when engaged in their secondary mission. The AMD can significantly improve the accuracy of orientation for the battery commander's telescope (BC Scope) and the HHLR provided a suitable mount is designed to place both equipments on the BC Scope or an additional tripod is provided for the AMD and HHLR. The addition of a GPS User Unit in addition to the EPUU does not appear to be cost effective. The GPS was retained in the analysis, however, to determine the impact of the improved self-location accuracy provided by the system.

4-10. Sound Ranging. Each of the two sound/flash platoons in the target acquisition battery (TAB) can install two sound bases of up to six microphones each. Since only one base can be operated for extended periods of time due to personnel limitations, a leap frog method of employment is normally used for continuous operations. The fielding of PADS and the Radio Data Link, AN/GRA-114 marks a significant increase in the capability to employ the Army's only passive means of locating hostile weapons. A sound base can be operational in approximately one hour, with these equipments, versus six - eight hours with traditional survey and wire-laying equipment.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
PLRS	PADS

b. Current doctrine for sound base operations states that microphone locations will be determined by map inspection, prior to completion of survey operations, and a hasty base method of operations be used. This method of operations is undesirable in that the lack of a common grid with the firing units precludes immediate fire for effect on targets located by the base. A sound on sound adjustment technique is used instead. It appears that use of the PADS will eliminate the need for hasty techniques in that the base can be surveyed by the time microphones are installed and the sound central readied for operation. In the event that PADS is not available, the logical choice for hasty survey is PLRS because it establishes a common grid with firing units. However, target location accuracy may be degraded with PLRS data. The map is retained as a hasty survey method because of availability. The survey party is rejected because its response time is unacceptable.

c. Systems selected for further analysis are:

HASTY	DELIBERATE
Map	PADS
PLRS	

d. The Global Positioning System is the only alternative system applicable to sound ranging. It appears, based on a review of available documentation, that the GPS will provide significantly improved location data, compared to that available from PLRS/PJH. The use of one or more User Units in the sound ranging platoon offers the potential of significantly reducing the time required for sound base survey as well as freeing PADS assets to satisfy other requirements.

4-11. Remotely Piloted Vehicle (RPV). The Target Acquisition/Designation and Reconnaissance System, YMQM-105 (TADARS), is an armored, infantry, mechanized infantry (AIM) division artillery TAB system designed to acquire targets and other combat information beyond line of sight of supported ground forces in real time while reducing the exposure of manned aircraft to enemy ADA fire. There are four sections in the platoon, each capable of independent operations. One section is normally employed in each brigade area (attached to FA battalion) while the fourth section provides general support to the division artillery. Each section includes an air vehicle(s) and sensor package(s), ground control element, launch and recovery subsystems, associated ground support equipment and sufficient personnel to operate and maintain the system hardware. The ground control element includes a remote ground terminal (RGT) which may be separated from the ground control station (GCS) by up to 750 meters. The survey requirements at table 4-2 are stated for the RGT. Section equipment includes the map, compass, PLRS User Unit, and the T16 theodolite, utilized to orient the RGT antenna. The TADARS is designed to operate the air vehicle 20km beyond the forward line of troops (FLOT).

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
PLRS	SIAGL
Aiming Circle	PADS

b. Responsibility for RPV survey requirements is split between host FA battalions and tne TAB. Survey parties in either element can satisfy orientation and position accuracy requirements, however, survey response time, as measured by the FSMAA analysis, Appendix 1, which does not include the RPV, is inadequate. A one-hour waiting time is stated in the analysis. The waiting time may be reduced to some extent by the fact that section movements are planned and advance notice of the requirement should facilitate earlier completion of RPV survey operations. PADS is the obvious choice of deliberate systems because of its accuracy and response time. Other methods of providing azimuth (SIAGL and astronomic observation) must be evaluated to determine if the improvement accuracy provides a significant improvement in effectiveness. Base case hasty systems are retained for analysis to determine the impact of decreased accuracy on system operations.

c. Systems retained for further analysis are:

HASTY	DELIBERATE
Map	PADS
Aiming Circle	SIAGL
PLRS	

d. The PJH, AMD and GPS are considered alternatives for the RPV.

(1) The PJH is the follow-on system to PLRS and, as discussed earlier in the analysis, becomes the digital communications system for the division.

(2) The AMD, as currently envisioned, will satisfy the RGT orientation requirement. It also offers the advantage of being a low cost device which can be mounted on the system to satisfy orientation requirements in real time.

(3) The GPS offers significantly improved position accuracy over the PJH system.

4-12. Moving Target Locating Radar (MTLR). The TAB radar platoon contains one MTLR, either the AN/TPQ-25 or 58 radar. The radar is normally positioned on commanding terrain on a major avenue of approach into the division area. The

TPS-25A radar can locate moving targets to within 100 meters, however, a manual prediction of future target location is usually required if the target is attacked by FA. The TPS-58 is an improved radar which can locate targets within 50 meters and predict target locations. The maximum range of the TPS-58 radar is 20km; 18,280 for the TPS-25A. Both radars must be positioned to achieve electronic line-of-sight into the area to be observed and are, therefore, extremely vulnerable to enemy countermeasures and subsequent attack unless moved frequently. Section equipment includes the map, compass, aiming circle, and PLRS User Unit.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
Compass	SIAGL
Aiming circle	PADS
PLRS	

b. Frequent use of hasty survey data can be expected. The section will be required to move frequently to avoid counterfire and the average waiting time for survey, extracted from the FSMAA, is approximately one hour. The most responsive hasty survey system appears to be PLRS for position and the aiming circle for orientation. None of the deliberate survey systems can satisfy response time requirements. PADS offers the best opportunity because of the speed of operations, however, the PADS assets will often be utilized on higher priority survey requirements.

c. The following systems were retained for further analysis:

HASTY	DELIBERATE
PLRS	PADS
Aiming Circle	

d. The PJH, AMD and GPS are the alternative systems applicable to the MTLR.

(1) The PJH replaces PLRS as previously discussed.

(2) The AMD can satisfy orientation requirements in both accuracy and time. This system, coupled with the GPS or PJH, can provide all orientation and position data required, thus freeing PADS to concentrate on higher priority systems.

(3) The GPS will provide a more accurate solution than the PJH.

4-13. Mortar Locating Radar (MLR). Three AN/TPQ-36 radars are authorized in the target acquisition battery of each division. The usual method of employment is to attach one radar to each FA battalion with a mission of direct support. The radar range is classified, however, it is significantly improved over its predecessor system, the AN/TPQ-4A. The accuracy of orientation data, therefore, assumes greater importance. The radar is normally assigned a mission of locating relatively short range hostile weapons while its sister radar, the AN/TPQ-37, concentrates on longer range weapons. These highly effective radars will be a countermeasures target and frequent moves can be expected to counter this threat. The MLR section is equipped with the map, compass, aiming circle and PLRS User Unit.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
Aiming Circle	SIAGL
PLRS	PADS

b. The host FA battalion is responsible for satisfying MLR survey requirements. Hasty systems cannot satisfy orientation or positioning accuracy requirements. Orientation accuracy requirements can be satisfied by the SIAGL or the survey party and position accuracy requirements can be met by the survey party, and PADS. The FSMAA analysis, Appendix 1, indicates an average waiting time of 54 minutes for survey data for positions surveyed by the battalion survey section, equipped with one PADS and one survey party. (A requirement for one primary and two alternate positions was included in the FSMAA analysis.) This survey response time will cause frequent use of the aiming circle for hasty orientation data and the PLRS for position data. Map inspected position data does not satisfy accuracy requirements, however it should be retained for further analysis since it is readily available.

c. All the systems listed in a, above, were retained for further analysis.

d. The PJH, AMD and GPS are applicable to the MLR.

(1) The PJH replaces PLRS as previously discussed.

(2) The AMD cannot satisfy the MLR orientation requirement of 0.3 mils PE. It can satisfy the response time requirement and should be considered to determine the impact of the accuracy shortfall. Use of the AMD in conjunction with the PJH may provide a satisfactory hasty survey system for the radar at little loss of effectiveness, pending availability of improved survey data.

(3) The GPS will provide improved position accuracy data and should be considered to determine the impact of the improved accuracy vice use of PJH.

4-14. Weapon Locating Radar (WLR). Two AN/TPQ-37 radars authorized in the target acquisition battery of each division. These radars are normally employed under the operational control of the division artillery tactical operations center (TOC) and are positioned to cover the width of the division front. Position areas are 8-12km behind the FLOT. The radar section will concentrate its location efforts on areas not covered by, or beyond the range capability of the AN/TPQ-36 radar. The significantly greater range capability of the AN/TPQ-37 is reflected in the orientation accuracy criteria (table 4-2) which is approximately 50 percent greater than that for the Q-36. The radar will be a countermeasures target and will move frequently to enhance survivability. The WLR section is equipped with the map, compass, aiming circle, and PLRS User Unit.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
Aiming Circle	SIAGL
PLRS	PADS

b. The TAB is responsible for AN/TPQ-37 survey. Hasty systems cannot provide the accuracy required for either orientation or position; on the other hand only hasty systems can meet the radar response time. The FSMAA analysis, appendix 1, indicates that the wait time for data on positions surveyed by the division artillery survey parties (includes TAB survey parties) is over one hour. Degraded position data can be provided initially by the PLRS followed by improved data from PADS or the survey party. Orientation accuracy requirements are stringent and can only be met by the SIAGL or the survey party with standard techniques to include astronomic observation, weather conditions permitting. The vertical position requirement is also stringent and can only be met by deliberate systems. Map inspected position data does not satisfy accuracy requirements, however it should be retained for further analysis since it is readily available.

c. All the systems listed above were retained for further analysis.

d. The analysis of alternative systems for the WLR is similar to the previous analysis for the MLR.

(1) The PJH replaces the PLRS as previously discussed.

(2) The AMD cannot satisfy the WLR orientation accuracy requirement of 0.15 mils PE. It can satisfy the response time requirement and should be considered to determine the impact of the accuracy shortfall. Use of the AMD in conjunction with the PJH or GPS may provide a satisfactory hasty survey system for the radar at little loss of effectiveness pending availability of improved survey data.

(3) The GPS should be considered for the same reasons discussed in the MLR analysis.

4-15. Meteorological Data System (MDS). Two systems are assigned to the TAB and one to the HHB, FA Brigade. The sections are deployed across the division area and provide meteorological data to target acquisition and firing units. Section equipment is passive and the sections move only in response to the tactical situation. Section equipment includes map, compass, aiming circle and the ML 474/GM Theodolite. The theodolite, normally used for back-up visual flights, is oriented by magnetic means.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
Compass	SIAGL
Aiming Circle	PADS
PLRS	

b. The MDS is normally positioned near a FA battalion which can provide survey support, if required. Orientation and position accuracy requirements can be met by hasty systems if the PLRS pr GPS User Unit is added to section equipment.

c. The AMD is a candidate system for the MDS only to determine if the increased accuracy from a low cost device is significant. The PJH replaces the PLRS for reasons previously discussed.

4-16. Self-Propelled Howitzer Battery. In the 1986 force structure the howitzer batteries are organized into two four-howitzer platoons to obtain increased firepower and provide increased dispersion of weapons for survivability purposes. Concepts for the post-1986 time period envision further improvements in survivability through increased dispersion of the howitzers. These concepts cannot be implemented until more responsive methods of orienting and surveying the weapons are fielded. In the near term 1982-86, howitzers will continue to be oriented and surveyed by traditional means or PADS, where available. In either case, horizontal and vertical position data is required for each platoon center and an orienting line must be established for each platoon. Howitzer battery personnel are responsible for determining position data for each howitzer using hasty survey methods. These include use of the battery computer system to compute individual howitzer positions given the distance, direction and vertical angle to each weapon from the orienting station.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
Compass	SIAGL
AC	PADS
PLRS	

b. Cannon artillery has been, and will continue to be, the maneuver commander's primary means of fire support. The requirement for immediately responsive fire support dictates that weapons be available to fire as soon as possible after occupation of position. The slow response time of the survey party and SIAGL have, in the past, caused extensive use of hasty survey methods to achieve the required weapon responsiveness. The PADS provides a quantum increase in survey capability. Assuming present POM procurement funding is maintained, the system will be fielded in all active duty units in calendar year 1987. The adequacy of the current PADS basis of issue was evaluated in the Fire Support Mission Area Analysis (FSMAA). The evaluation, appendix A, was based on a map exercise evaluation of a division slice of 3 x 6 cannon battalions survey section's capability to support weapons movements during a 48-hour period of the SCORES Europe I, Sequence 2A, Scenario. The results of the evaluation are listed at table 4-4 below, extracted from page 4-55 of the FSMAA Report.

Table 4-4. Battalion level survey (Figure 4-34, FSMAA).

Mix	Required Positions	Positions Closed	No Wait Time	Avg Waiting Time (mins)
Conventional Only	131	92	10	100
Conventional and PADS	135	133	80	54

As shown above, conventional parties failed to close (complete survey) for about 30 percent of the divisional and non-divisional artillery positions required, whereas almost all positions were surveyed with the conventional and PADS mix. The 3 x 8 cannon battalions in the division 86 force structure will be authorized three PADS instead of the one used in the FSMAA evaluation. The deployment of one PADS per firing battery should eliminate most survey waiting time.

c. Equipment failures/shortages, more frequent movements, etc. may still cause use of hasty survey methods in the cannon battery. A variety of methods, discussed in FM 6-50, THE ARTILLERY CANNON BATTERY, can be utilized. The most responsive means of obtaining a hasty direction is the magnetic needle on the aiming circle, followed by one of the forms of astronomic observation or the SIAGL. Horizontal and vertical position data is available from PLRS.

d. The following systems were retained for further analysis:

HASTY	DELIBERATE
Map Aiming Circle PLRS	PADS

e. The PJH, AGPS and GPS are alternative systems for the self-propelled howitzer battery.

(1) The PJH replaces the PLRS for the reasons previously stated.

(2) The AGPS will be fielded under the M109A3 HELP PIP. The system will replace the aiming circle as the primary means of laying (orienting) the howitzer and will cause the survey requirements to change from survey of the battery/platoon center to survey of initialization and update points for the AGPS. Once initialized the AGPS should provide the required orientation and position accuracy for distances up to 15km, before use of an update point is required to correct system errors. This system will significantly improve the flexibility of positioning and simplify survey support. Control points can be established on or near roads and trails instead of cross-country movements to battery centers.

(3) The PJH and GPS are considered for two methods of employment. The first, the establishment of initialization/update points, is the logical near term usage. The second, a long term effort, could incorporate the user unit into the AGPS unit on board the howitzer.

4-17. Towed Howitzer Battery. Towed howitzer batteries will also be organized in two-four howitzer platoons in the 1986 force structure. The base case analysis for the towed weapon is similar to that presented for self-propelled weapons. One apparent difference in the analysis is a reduction in the amount of time hasty survey data must be used. Towed weapons do not normally move as often or as far as SP weapons, therefore, the amount of time a unit waits for survey, given the same PADS assets, should be less for the towed battery. Given these considerations the survey systems retained for the towed battery are the same as those previously selected for the self-propelled weapon.

a. The PJH, GPS and AMD are alternative systems for the towed howitzer battery.

(1) The PJH replaces the PLRS for the reasons previously stated.

(2) An on-board fire control/land navigation system, such as the AGPS, is not viable for the towed howitzer, therefore, the AMD is considered as an alternative means for improving the orientation accuracy of the howitzer. The DPROC for the AMD states a requirement for mounting the AMD on the aiming circle. The AMD would be used to orient the aiming circle, which, in turn, is used in the usual manner to lay (orient) the howitzers. A research and development effort is required to validate this concept.

(3) Position location with GPS will be investigated as a part of the self-propelled howitzer analysis.

4-18. Multiple Launch Rocket System (MLRS). The MLRS self-propelled launcher loader (SPLL) is the first FA weapon designed with an on-board fire control, orientation and position locating system. The function of the SRP/PDS, described at paragraph 3-2f, Chapter 3, is to provide orientation and position data to the fire control system for use in computing fire commands and laying (orienting) the launcher-loader module in azimuth and elevation. The SPLL design does not include an alternative orientation system, i.e. an aiming circle cannot be used to orient the weapon sight.

a. Candidate base case systems are:

HASTY	DELIBERATE
PLRS	SRP/PDS
	PADS

b. System performance is dependent, in part, upon the establishment of survey control points for use in initialization/calibration of the SRP/PDS. One PADS per MLRS battery is authorized for this purpose and should be adequate, assuming starting control for PADS is available. If this control is not available from previously established control points the FSMAA analysis (para 4-11b) indicates that approximately one hour of waiting time may occur, based on present level of PADS employment. Initial control, suitable for SRP/PDS initialization, can be established with hasty resection techniques or the PLRS User Unit, available in each firing platoon. The use of PLRS is preferred because it places the platoon on a common grid with other agencies. The PADS can then be used to establish the required calibration points. Calibration points are required for each platoon and must be established 2.5 to 4 km apart to an accuracy of 1 meter relative error per 1000 meters between the points.

c. The base case systems were retained for analysis. The hasty resection was not added as a hasty system because the position accuracy would be similar to that provided by PLRS.

d. The PJH and GPS are alternative systems for MLRS.

(1) The PJH replaces PLRS for reasons previously stated.

(2) The improved position accuracy of GPS should be evaluated with respect to its use in establishment of initialization points for MLRS.

4-19. LANCE Missile Battalion Survey. The LANCE Missile Battalion is a corps artillery asset. Three batteries, two launchers each, will be employed across the corps front. Batteries may be positioned in the corps or division area. When positioned in the corps area, the battery relies on the use of existing survey control points and new control established by the engineer topographic survey platoon. The division artillery is responsible for survey control points when the batteries are positioned in the division area. The following statement, extracted from paragraph I-5a, FM 6-2, states the importance of survey in LANCE units. "The relatively long range of the missile with either a nuclear or non-nuclear warhead, coupled with the intertial guidance system and relatively small probable error, requires that surveyed locations be determined for each launcher position and an accurate direction be provided for orientation of the missile." Except for the possible use of map inspection for position determination, the use of hasty survey methods, described in this analysis, are not suitable for LANCE survey operations.

a. Candidate base case systems are:

HASTY	DELIBERATE
Map	Survey Party
	SIAGL
	PADS

b. The use of map inspected position location for LANCE is considered a last resort because of the error associated with this method. This analysis cannot support the assertion, at paragraph I-6, FM 6-2, that the accuracy of this method is 50-60 meters, (see paragraph 3-2a for a discussion of map reading accuracy). This appears revelent only if survey control points are not available and the tactical importance of the weapon dictates that every effort be made to provide these points. The primary method of providing position will be PADS (one system per battery) and the primary method of providing orientation (0.3mil PE required) must be the SIAGL, astronomic observation, or directional traverse from suitable survey control points. The speed of survey operations with PADS favors the use of PADS data for both position and orientation, therefore this analysis must consider the impact on system effectiveness when using a PADS orientation (0.4mil PE) versus SIAGL, astronomic observation, etc. (0.12/0.06 mil PE).

c. The following systems were retained for further analysis:

HASTY	DELIBERATE
None	Survey Party SIAGL PADS

d. The G[illegible] is the only applicable alternative for LANCE. If GPS provides position data to sufficient accuracy for LANCE, the system could replace PADS by placing user units in the firing section and SIAGL, or an improved azimuth measuring device, in the firing section.

CHAPTER 5

EFFECTIVENESS ANALYSIS

5-1. PURPOSE. This chapter will determine and compare the error introduced by alternative methods of survey, discuss the impact of the errors on artillery effectiveness, consider other factors such as responsiveness and relative cost, and recommend the appropriate survey system(s) for each user.

5-2. MEASURES OF EFFECTIVENESS (MOE).

a. MOE #1. Survey CEP (SCEP).

(1) SCEP was chosen as the MOE to compare the total error introduced by various survey methods. SCEP is defined as follows:

MOE #1: SCEP. The amount of "on-target" error introduced by the positioning and orientation of an FA system when that system becomes involved in a subsequent fire mission.

A more detailed description, as well as the algorithm used to compute SCEP, is presented in Appendix B.

(2) The Appendix B methodology is not appropriate for some FA systems such as sound ranging or the Meteorological Data System (MDS), therefore, alternate methodologies for these systems are addressed within this chapter.

b. MOE #2 and MOE #3. First-Round CEP (FRCEP) and One-Round Adjust CEP (ORCEP).

(1) For MET+VE non-adjust fire missions, SCEP contributes in full to the overall mission error. When an adjustment capability exists, such as with ground observers, the SCEP contribution is not so straightforward. The observer may opt to "shoot-out" most of the mission error (including SCEP) with adjustment rounds. He may, on the other hand, opt to fire first volley fire-for-effect (FFE).

(2) First volley FFE is desired because it offers the advantage of surprise fire. If adjustment rounds are fired prior to FFE volleys, the enemy has an opportunity to reduce their vulnerability. Despite losing the element of surprise, however, "adjust" missions will be more frequent than first-volley FFE missions when observation is available. Historically, the major portion of adjustment rounds are consumed by "bracketing" for range corrections. This is due to the ground observer's lacking ability to accurately estimate distance. With the advent of laser range finders, this problem will be reduced significantly. One-round "adjust" missions are expected to be a common procedure.

(3) First-Round CEP (FRCEP) and One-Round Adjust CEP (ORCEP) were chosen as the MOE's to compare the overall mission errors before and after a single adjustment round when various survey methods are employed. These MOE's are defined as follows:

MOE #2 (FRCEP): The total delivery error of the initial adjust round on a ground observer "adjust" mission. The ground observer's self-location error, his target location error relative to self, and weapon system delivery errors all contribute to FRCEP.

MOE #3 (ORCEP): The total delivery error of a fire-for-effect volley center after one round of adjustment.

(4) The methodology for computing FRCEP and ORCEP is presented in Appendix C. FRCEP's and ORCEP's were computed for each ground observer survey method identified in chapter 4 with all possible distance/direction measuring devices considered. Whereas SCEP comparisons will be made for all survey users, FRCEP and ORCEP are strictly for ground observers.

c. MOE #4. Expected Fractional Casualties (EFC).

(1) EFC was selected as the MOE to compare the impact of various survey errors on artillery effectiveness. This MOE is defined as follows:

MOE #4 (EFC): The expected fraction of target area elements destroyed for a "standard" artillery mission.

(2) The difficulty in examining survey error's impact on effectiveness lies in the definition of "standard" artillery mission. Artillery effectiveness depends on a number of mission characteristics such as the size and geometry of the target area, the vulnerability of elements within the target, and the accuracy of the target acquisition system. The complexity of the problem is compounded by the numerous response methods possible, i.e., the impact varies for different weapon systems firing different ammunitions at various gun-target ranges. Obviously, it is too time consuming a. expensive to evaluate each of the several artillery weapon systems and firing conditions encountered. It is equally difficult to assess each of the many various types of targets presented to the artillery.

d. Appendix D presents an analysis to scope the problem by defining a "standard" artillery mission. Median conditions were selected as nearly as possible. Conditions most critical to the analysis were parameterized to bound the solution.

5-3. RELATIONSHIP OF MOEs.

a. Time and expense prohibited EFC computations for each individual survey user/survey method combination considered. Instead, EFC curves were generated to show the impact of survey errors on artillery effects.

b. First EFC curves were generated as a function of SCEP. The purpose was to show the impact of SCEP when the subsequent artillery mission is MET+VE unadjusted. An additional EFC curve was generated strictly for ground observer missions. This curve is presented as a function of mission-to-mission CEP. The mission-to-mission CEP of a one-round "adjust" mission is represented by ORCEP. The mission-to-mission CEP of an observer first-round FFE mission is represented by FRCEP. For either option considered, this additional EFC curve, to be referred to as the OBSERVER EFC curve, is used for comparison of artillery effectiveness resulting from the various ground observer survey methods. Both FRCEP and ORCEP are used as entry values to the OBSERVER EFC curves.

c. The methodology for computing both types of EFC curves is presented in the following paragraph. The actual curves are also presented. Analysis discussions in later paragraphs will then reference these curves as often as necessary.

5-4. EFC CURVES.

a. Model Description. A deterministic artillery effectiveness model, QUICKIE, was used to compute EFC. Inputs to QUICKIE specify an artillery attack against an area target. These inputs include target descriptors, target location error, volley geometry, number of volleys, and capabilities of the weapon system and ammunition. Under these input-specified conditions, QUICKIE calculates the expected fractional casualties of target elements uniformly dispersed in the target area. SCEP EFC curves were derived by varying the SCEP in successive QUICKIE runs while all other inputs describing a "standard" mission were held constant. SCEP EFC curves are presented in paragraph 5-4b. In a similar manner, mission-to-mission CEP was varied to produce the OBSERVER EFC curve. The OBSERVER EFC curve is presented in paragraph 5-4c.

b. Presentation of SCEP EFC Curves. Since certain factors strongly influence the "steepness" of an SCEP EFC curve, Appendix D recommends four "standard" artillery missions instead of just one. Each of the four "standard" missions are similar except for the following differences:

(1) "Best case" MPI error conditions and a 50 meter target radius.

(2) "Worst case" MPI error conditions and a 50 meter target radius.

(3) "Best case" MPI error conditions and a 150 meter target radius.

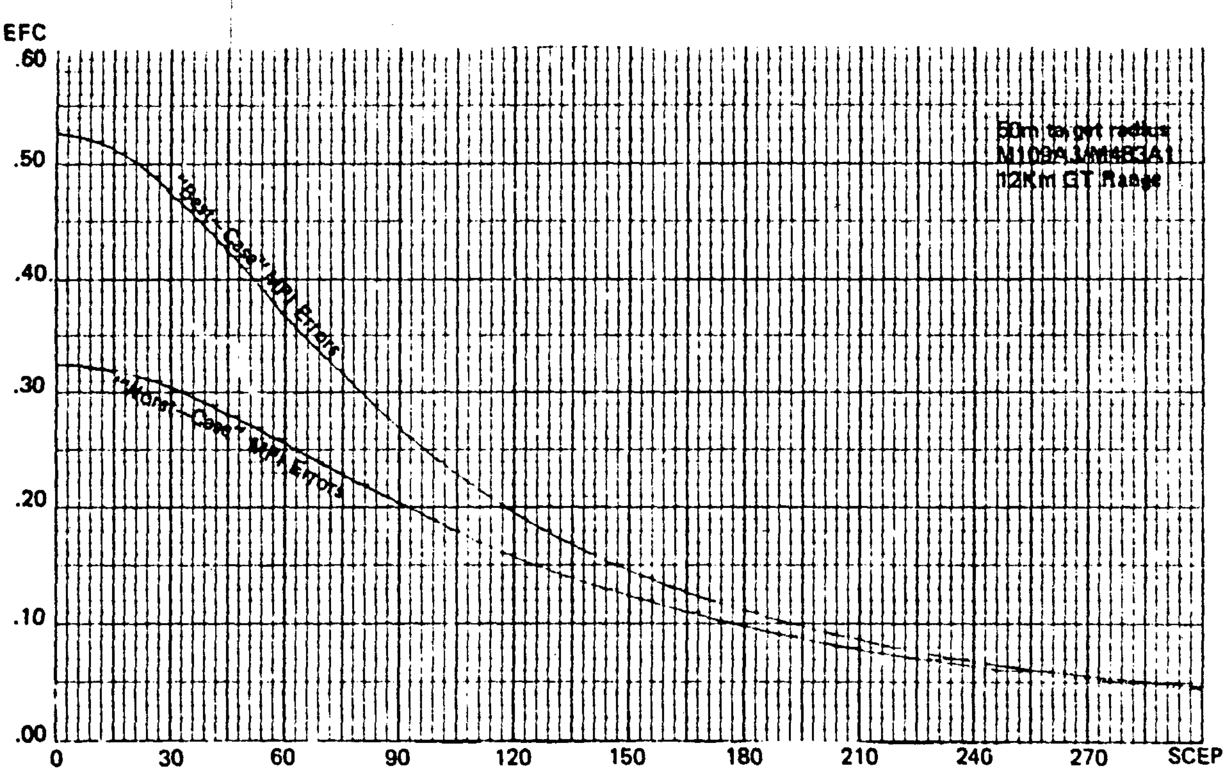
(4) "Worst case" MPI error conditions and a 150 meter target radius.

SCEP EFC curves for "standard" missions #1 and #2 are presented in Figure 5-1. SCEP EFC curves for "standard" missions #3 and #4 are presented in Figure 5-2. The most sensitive curve is that associated with "standard" mission #1. The least sensitive curve belongs to "standard" mission #4. The relative loss in effectiveness, as a function of SCEP, is summarized for these extreme cases in Table 5-1 for convenience in later discussions.

Table 5-1 -- Relative loss in EFC due to SCEP

SCEP	EFC Values for "Standard" Mission		Percent Loss in EFC for "Standard" Mission	
	#1	#4	#1	#4
0	.526	.306	-	-
10	.519	.305	1	-
20	.503	.302	4	1
30	.475	.297	10	3
45	.424	.286	19	7
60	.368	.272	30	9
75	.316	.255	40	15
90	.269	.238	49	20
120	.196	.207	63	32
150	.146	.169	72	45
180	.111	.141	79	54
210	.087	.118	83	61
240	.069	.099	87	68
270	.057	.084	89	73
300	.047	.071	91	77

Figures 5-1 and 5-2 and Table 5-1 are referenced in later analysis discussions involving survey users other than ground observers.



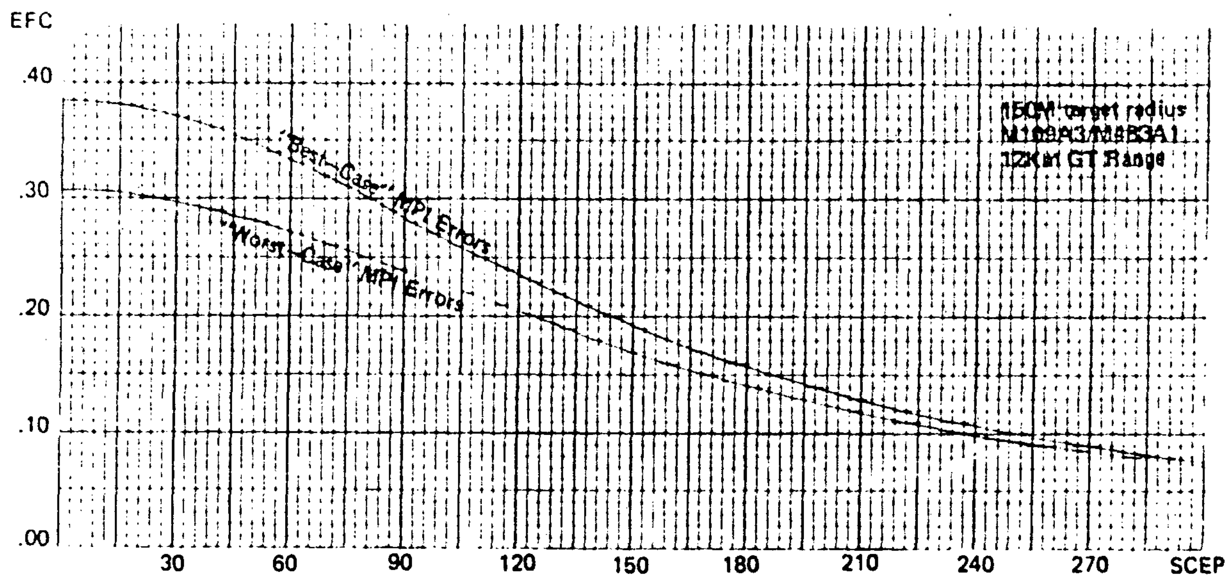


Figure 5-2. SCEP EFC curves for "standard" missions #3 and #4

c. Presentation of the OBSERVER EFC Curve. In general, the same "standard" artillery mission used to compute SCEP EFC curves was also used to compute the OBSERVER EFC curve. There were, however, some exceptions. One exception involves target size. Whereas SCEP EFC curves were generated for both 50 meter and 150 meter target radii, the OBSERVER EFC curve was generated only for the 50 meter target radius. The 150 meter target radius was not considered because ground observers seldom locate large area targets. Another exception is the definition of the "worst-case" MPI error condition. As described in paragraph 2h of Appendix D, the "worst-case" MPI error condition includes an "additional" 50 meter CEP used to account for target location error other than SCEP. This "additional" 50 meter CEP was not applied to "worst-case" MPI error for OBSERVER EFC computations. This avoids double-counting target location error since computations of FRCEP and ORCEP (see Appendix C, Methodology), the entry values to the OBSERVER EFC curve, previously consider all target location errors. Note also that FRCEP's and ORCEP's are computed for both "worst-case" and "best-case" MPI error conditions. This allows a single OBSERVER EFC curve to suffice for both MPI error conditions. The OBSERVER EFC curve is presented in Figure 5-3. Figure 5-3 is referenced in later analysis discussions involving ground observers.

5-5. METHOD OF PRESENTATION.

a. To simplify the presentation of data and results, each survey user is addressed separately. Within each subanalysis discussion, the following is accomplished for the various survey methods identified in Chapter 4:

(1) SCEP's are presented and compared.

(2) SCEP's (or FRCEP's and ORCEP's) are used in conjunction with EFC curves for effectiveness comparisons.

(3) Availability and responsiveness is discussed.

(4) Survey methods are prioritized.

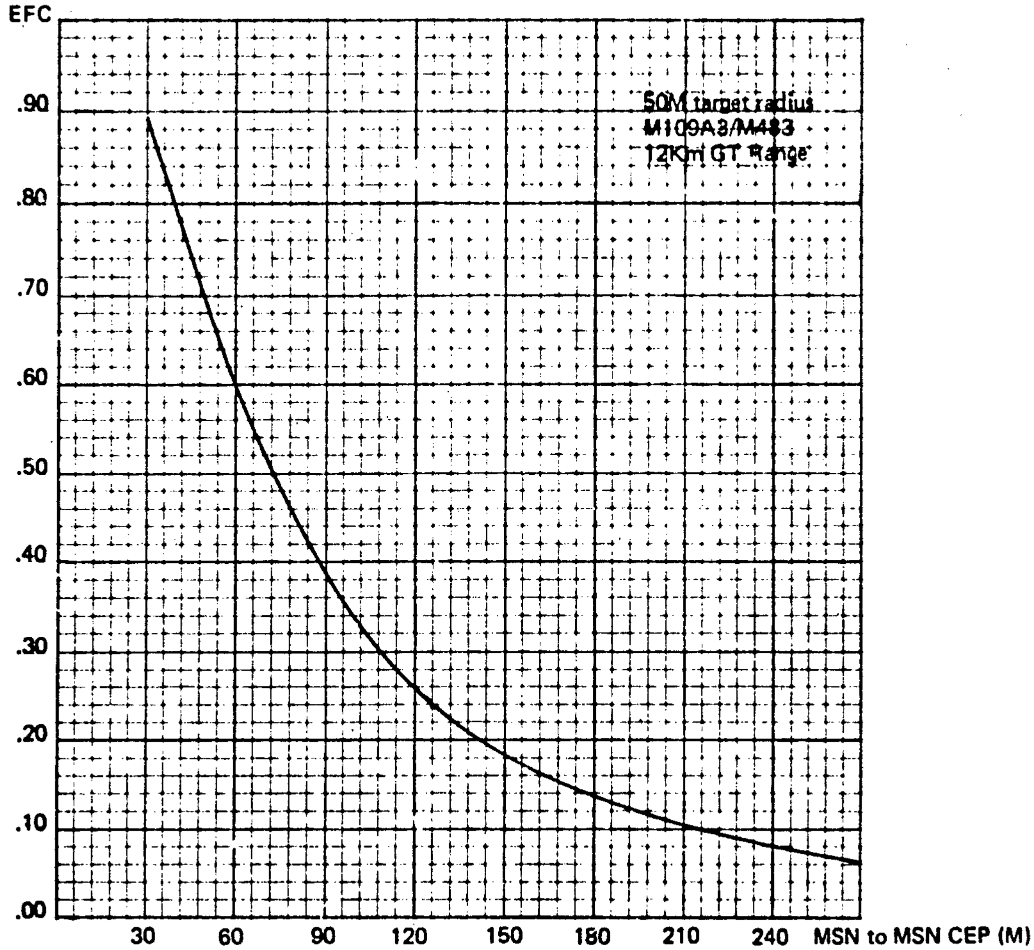


Figure 5-3. Observer EFC curve

Some subanalysis will require modifications or excursions from steps 1 and 2 of the above-mentioned general approach. Special analysis to support necessary excursions are referenced from within specific subanalysis discussions.

b. The contributing input values and SCEP outputs are presented (see Table 5-2). Each input value is followed by a letter code in parenthesis. The letter code references a paragraph in Appendix E, which discusses the source and/or derivation of the input value.

c. FRCEP's and ORCEP's are presented for sub-analysis involving ground observers (see Tables 5-3 and 5-4). FRCEP's and ORCEP's are presented for each survey method identified in Chapter 4 with all possible distance/direction measuring devices considered. The values, presented in pairs separated by a dash, are for "best-case" and "worst-case" MPI error conditions, respectively.

d. If a subanalysis involves ground observers, FRCEP's and ORCEP's are used in conjunction with the OBSERVER EFC curve (see Figure 5-3) to make effectiveness comparisons. To simplify the presentation of EFC values, FRCEP and/or ORCEP entry values used are the average of "best-case" and "worst-case" values. In cases where the HHLR is used, HHLR-1 and HHLR-2 values are also averaged.

e. If a subanalysis does not involve ground observers, SCEP's are used in conjunction with SCEP EFC curves (see Figures 5-1 and 5-2 and Table 5-2) to compare relative losses in effectiveness attributable to the SCEP's associated with the various survey methods considered.

5-6. GROUND OBSERVER WITHOUT THE GROUND LASER LOCATOR DESIGNATOR (GLLD).

a. Survey System Performance. (Table 5-2)

(1) None of the base case system SCEP's meet the required SCEP.

(2) The most accurate base case system (2 point LRF) depends upon the availability of external reference points. Without reference points, a less accurate method, map inspection of coordinates and use of the compass for direction, (map spot and compass) will be used.

(3) Resection is not an accurate survey method when a compass is used for direction measurements.

(4) All methods involving AMD-3, with the exception of map spot, will meet the required SCEP.

(5) In the event that no reference points are available, the map spot SCEP is improved by replacing the compass with the AMD-3 for orientation.

(6) Resection is an accurate survey method when an AMD-3 is used for direction measurement.

(7) PJH, when used in conjunction with a compass, will improve SCEP and eliminate the dependence on external reference points, but it will not meet the survey requirement.

(8) PJH, used in conjunction with an AMD-3, will satisfy the survey requirement under all conditions. If the AMD-3 is not available, the survey requirement will not be satisfied due to inaccurate orientation. If the PJH is not available, the survey requirement can only be met when reference points are available.

Table 5-2. SCEP values for ground observer without GLLD. OT range 2 km (a)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEø) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	87.5(b)	-	10.0 (b)	-	20.0(b)	-	97
Base Case Methods:							
2PT LRF w/HHLR-1/Compass	30.9(g)	-	54.15(d)	-	10.0(e)	-	115
2PT LRF w/HHLR-2/Compass	82.9(g)	-	54.15(d)	-	10.0(e)	-	146
Polar Plot w/HHLR-1/Compass	134.2(h)	-	54.15(d)	-	10.0(e)	-	184
Polar Plot w/HHLR-2/Compass	143.9(h)	-	54.15(d)	-	10.0(e)	-	192
Map Spot and Compass	150.0(i)	-	54.15(d)	-	10.0(e)	-	197
Resection w/Compass	187.3(c)	-	54.15(d)	-	10.0(e)	-	227
Alternate Methods:							
Resection w/AMD-3	20.7(c)	-	1.35(f)	-	10.0(e)	-	26
Polar Plot w/HHLR-1/AMD-3	26.0(h)	-	1.35(f)	-	10.0(e)	-	31
PJH and AMD-3	30.0(s)	-	1.35(f)	-	10.0(s)	-	34
2PT LRF w/HHLR-1/AMD-3	30.9(g)	-	1.35(f)	-	10.0(e)	-	35
Polar Plot w/HHLR-2/AMD-3	60.5(h)	-	1.35(f)	-	10.0(e)	-	63
2PT LRF w/HHLR-2/AMD-3	82.9(g)	-	1.35(f)	-	10.0(e)	-	85
PJH and Compass	30.0(s)	-	54.15(d)	-	10.0(s)	-	115
Map Spot and AMD-3	150.0(i)	-	1.35(f)	-	10.0(e)	-	151

b. Effectiveness Conclusions. First Round CEP (FRCEP) and One Round CEP (ORCEP) values are listed at tables 5-3 and 5-4. Average CEP values were used to determine the EFC values at table 5-5. The data at table 5-5 is summarized for the base case survey systems and three alternatives, discussed below.

(1) Base Case Methods Only. FRCEP EFC's are significantly lower than ORCEP EFC's. The resultant gain in accuracy of a one-round adjust procedure should more than compensate for the loss of surprise caused by the adjustment round.

(2) Case Two -- AMD available. If reference points are available, the AMD will significantly improve base case FRCEP EFC's. This gain would make first round Fire for Effect (FFE) a viable alternative in situations where "warning" causes drastic changes in target posture. If reference points are not available, the use of the AMD results in some improvement over the base case FRCEP EFC's. Use of the AMD results in a nine percent improvement over base case ORCEP EFC's.

(3) Case Three -- PJH Available. If two reference points are available, use of the PJH does not improve base case FRCEP and ORCEP EFC's. If none or one reference point is available, use of PJH results in some improvement over base case FRCEP EFC's. The use of PJH does not improve base case ORCEP EFC's.

(4) Case Four -- PJH and AMD Available. Regardless of the number of reference points available, simultaneous use of PJH and the AMD will significantly improve base case FRCEP EFC's. This gain would make first round FFE a viable alternative in situations where warning caus s drastic change in target posture. The simultaneous use of PJH and the AMD results in a nine percent improvement over base case ORCEP EFC's.

Table 5-3. First round CEP (FRCEP) values for various survey methods and equipments. OT range of 2km ground observer without GLLD

	EQUIPMENT			
SELF-LOCATION	HHLR-1		HHLR-2	
METHOD	AMD-3	COMPASS	AMD-3	COMPASS
Resection	89.4-109.2	246.6-254.6	104.1-121.8	251.0-258.6
2PT LRF	92.1-111.5	160.8-172.6	132.3-146.6	185.4-195.7
Polar Plot	92.1-112.2	206.8-216.1	118.6-133.9	219.0-227.9
Map Spot	173.7-184.9	216.5-225.5	182.2-193.0	223.9-232.7
PJH	92.9-111.8	160.8-172.8	106.5-123.8	169.6-180.8

Table 5-4. One round CEP (ORCEP) values for various survey methods and equipments. OT range 2km, ground observer without GLLD

SELF-LOCATION METHOD	HHLR-1 AMD-3	HHLR-1 COMPASS	HHLR-2 AMD-3	HHLR-2 COMPASS
Resection	36.5-36.7	45.5-46.0	85.3-85.4	89.7-90.0
2PT LRF	36.3-36.5	43.2-43.3	85.6-85.8	88.4-88.5
Polar Plot	36.7-36.9	44.0-44.4	86.0-86.1	88.5-88.7
Map Spot	38.4-38.8	44.6-44.9	85.7-85.9	89.6-89.8
PJH	36.4-36.6	43.5-43.6	85.5-85.5	88.4-88.5

Table 5-5. Expected fraction of casualties (EFC) for average FRCEP/ORCEP values for various survey/methods, ground observer without GLLD

CASE I: Base case methods only.

# Ref Pts Available	Survey Method	FRCEP	FRCEP EFC	ORCEP	ORCEP EFC
2	2PTLRF	179	.17	66	.55
1	Polar Plot	217	.09	66	.55
Ø	Map Spot	225	.09	67	.55
CASE II: AMD available.					
2	Resection	106	.31	61	.60
1	Polar Plot	114	.31	61	.60
Ø	Map Spot	183	.13	62	.60
CASE III: PJH available.					
2 or 1 or Ø	NA	171	.14	66	.55
CASE IV: AMD and PJH available.					
2 or 1 or Ø	NA	109	.35	61	.60

c. SubAnalysis Conclusions.

(1) The PJH system improves the survey capability by alleviating the observer's dependence upon external reference points.

(2) The AMD, with or without the PJH, improves FRCEP EFC significantly--to the point that first volley FFE becomes a viable option. The AMD also improves ORCEP largely due to the use of a tripod which improves adjustment accuracy.

(3) Weight restrictions on ground observers without vehicles prohibit the addition of an AMD to section equipment. The PJH weight, however, is not a problem since it replaces the PRC-77 radio on a one-for-one basis.

(4) Given the weight restrictions in (3) above, the best alternative system for observers without vehicles is PJH and the compass.

5-7. GROUND OBSERVER WITH GLLD.

a. Survey System Performance (Table 5-6).

(1) The results of the survey error analysis are similar to those stated for the ground observer without GLLD. SCEP's for the base case systems and alternative systems which utilize the compass for orientation and map spots are significantly higher than those in table 5-2 because of the longer observer to target range (2 versus 3 km).

Table 5-6. SCEP Values for ground observer with GLLD. OT range 3 km(a)

	HORIZONTAL CONTROL (CEPm)	TRF	AZIMUTH CONTROL (PEm)	TRF	VERTICAL CONTROL (PEm)	TRF	SURVEY (CEPm)
Accuracy Requirements	87.5(b)	-	10.0 (b)	-	20.0(b)	-	100
Base Case Methods:							
2PT LRF w/GLLD and Compass	21.5(g)	-	54.15(d)	-	10.0(e)	-	158
Polar Plot w/GLLD/Compass	133.6(h)	-	54.15(d)	-	10.0(e)	-	225
Map Spot and Compass	150.0(i)	-	54.15(d)	-	10.0(e)	-	236
Resection w/Compass	187.3(c)	-	54.15(d)	-	10.0(e)	-	264
Alternate Methods:							
Resection w/AMD-3	20.7(c)	-	1.35(f)	-	10.0(e)	-	26
Polar Plot w/GLLD/AMD-3	27.0(h)	-	1.35(f)	-	10.0(e)	-	27
ZPT LRF w/GLLD and AMD-3	21.5(g)	-	1.35(f)	-	10.0(e)	-	27
PJH and AMD-3	30.0(s)	-	1.35(f)	-	10.0(s)	-	34
Map Spot and AMD-3	150.0(i)	-	1.35(f)	-	10.0(e)	-	151
PJH and Compass	30.0(s)	-	54.15(d)	-	10.0(s)	-	162

b. Effectiveness Conclusions. First Round CEP (FRCEP) and One Round CEP (ORCEP) values are listed at tables 5-7 and 5-8. Average CEP values were used to determine the EFC values at table 5-9. The values in these tables closely approximate the values at tables 5-3 through 5-5 for the ground observer without GLLD. The only apparent difference in table 5-9 is the higher ORCEP EFC's, when compared to those in table 5-5. This difference is attributable to the improved adjustment accuracy made possible by the GLLD's excellent range-measuring capability. Other effectiveness conclusions are the same as those for the ground observer without GLLD.

Table 5-7. Values for various survey methods and equipments. OT range 3 km, ground observer with GLLD

SELF-LOCATION METHOD	EQUIPMENT GLLD/AMD-3	GLLD/COMPASS
Resection	88.2-108.3	287.6-294.5
2PT LRF	88.2-108.3	216.5-225.4
Polar Plot	88.5-108.7	254.5-262.6
Map Spot	172.3-183.3	261.0-268.7
PJH	91.6-111.4	217.7-226.9

Table 5-8. ORCEP values for various survey methods and equipments. OT Range 3 km, ground observer with GLLD

SELF-LOCATION METHOD	EQUIPMENT GLLD/AMD-3	GLLD/COMPASS
Resection	33.0-33.1	36.9-37.1
2PT LRF	33.2-33.3	35.6-35.6
Polar Plot	33.0-33.1	36.4-36.6
Map Spot	33.9-34.1	36.0-36.2
PJH	33.1-33.1	35.7-35.8

Table 5-9. EFC for average FRCEP and ORCEP values for various survey methods. Ground observer with GLLD

CASE I: Base case methods only.

# Ref Pts Available	Survey Method	FRCEP	FRCEP EFC	ORCEP	ORCEP EFC
2	2PT( )LRF	221	.09	36	.83
1	Polar Plot	259	.07	37	.82
Ø	Map Spot	265	.06	36	.83
CASE II: AMD available.					
2	Resection	98	.35	33	.86
1	Polar Plot	99	.34	33	.86
Ø	Map Spot	178	.13	34	.85
CASE III: PJH available.					
2 or 1 or Ø	NA	222	.09	36	.83
CASE IV: AMD and PJH available.					
2 or 1 or Ø	NA	102	.33	33	.86

c. Subanalysis Conclusions.

(1) The PJH system improves the survey capability by alleviating the observer's dependence upon external reference points.

(2) The AMD, with or without the PJH, improves FRCEP EFC significantly--to the point that the first volley FFE becomes a viable option. The AMD also improves ORCEP largely due to the use of the tripod-mounted GLLD which improves adjustment accuracy.

(3) Weight restrictions applicable to the ground observer without GLLD do not apply to the observer with GLLD since a vehicle is available for transport of the GLLD. The AMD will be mounted on the GLLD tripod and the AMD weight, 5 pounds, is insignificant compared to the total GLLD system weight, approximately 160 pounds. The PJH weight is not a problem since the PJH replaces an FM radio.

(4) The PJH and AMD-3 is the preferred survey system for the ground observer with GLLD.

5-8. FIRE SUPPORT TEAM VEHICLE (FISTV).

a. Survey System Performance (Table 5-10).

(1) All base case systems except map spot meet the required SCEP.

(2) The primary method, PLRS, is dependent upon the NSG to meet the required SCEP. When a compass is substituted for the NSG, the methods do not meet the SCEP.

(3) The PJH survey capability is identical to the PLRS survey capability.

(4) The SCEP is significantly improved by substituting GPS for PLRS/PJH.

Table 5-10. SCEP values for FISTV. OT range 3 km(a)

	HORIZONTAL CONTROL	(CEPm) TRF	AZIMUTH CONTROL	(PEm) TRF	VERTICAL CONTROL	(PEm) TRF	SURVEY (CEPm)
Accuracy Requirements	87.5(b)	-	10.0 (b)	-	20.0(b)	-	100
Base Case Methods:							
Resection w/NSG	20.7(c)	-	1.35(ii)	-	10.0(e)	-	26
2PT LRF w/GLLD and NSG	21.5(g)	-	1.35(ii)	-	10.0(e)	-	27
Polar Plot w/GLLD/NSG	21.0(h)	-	1.35(ii)	-	10.0(e)	-	27
PLRS and NSG	30.0(s)	-	1.35(ii)	-	10.0(e)	-	34
Map Spot and NSG	150.0(i)	-	1.35(ii)	-	10.0(e)	-	151
PLRS and Compass	30.0(s)	-	54.15(d)	-	10.0(s)	-	162
Alternate Methods:							
GPS and NSG	8.5(+)	-	1.35(ii)	-	10.0(t)	-	18
PJH and NSG	30.0(s)	-	1.35(ii)	-	10.0(s)	-	34
PJH and Compass	30.0(s)	-	54.15(d)	-	10.0(s)	-	162

b. Effectiveness Conclusions. First Round (FRCEP) and One Round CEP (ORCEP) values are listed at tables 5-11 and 5-12. Average CEP values were used to obtain the EFC values at table 5-13. The PLRS (PJH) and NSG FRCEP EFC values show that one-round FFE is a viable option. The ORCEP also shows an excellent adjustment capability. The substitution of GPS for PLRS/PJH increases the FRCEP EFC slightly but does not increase the ORCEP EFC.

Table 5-11. FRCEP values for various survey methods and equipments. OT Range 3 km, FISTV

SELF-LOCATION METHOD	EQUIPMENT GLLD/NSG	GLLD/COMPASS
Resection	88.2 - 108.3	287.6 - 294.5
2PT LRF	88.2 - 108.3	216.5 - 225.4
Polar Plot	88.5 - 108.7	254.5 - 262.6
Map Spot	172.3 - 183.3	261.0 - 268.7
PLRS (or PJH)	91.6 - 111.4	217.7 - 226.9
GPS	81.1 - 106.7	216.4 - 225.5

Table 5-12. ORCEP values for various survey methods and equipments. OT range 3 km, FISTV

SELF-LOCATION METHOD	EQUIPMENT GLLD/NSG	GLLD/COMPASS
Resection	33.0 - 33.1	36.9 - 37.1
2PT LRF	33.2 - 33.3	35.6 - 35.6
Polar Plot	33.0 - 33.1	36.4 - 36.6
Map Spot	33.9 - 34.1	36.0 - 36.2
PLRS (or PJH)	33.1 - 33.1	35.7 - 35.8
GPS	32.8 - 32.8	35.7 - 35.8

Table 5-13. EFC for average FRCEP and ORCEP values fo[illegible] [illegible]rious survey methods. OT range 3 km, FISTV

Survey Method	FRCEP	FRCEP EFC	OR	ORCEP EFC
CASE I: Base case methods only.				
PLRS and NSG	102	.33	33	.86
CASE II: GPS available.				
GPS and NSG	96	.36	33	.86

c. Subanalysis Conclusions.

(1) PLRS/PJH and the NSG provide adequate survey capability with no dependence upon external reference points and are responsive to mission needs.

(2) GPS offers a slight improvement to the survey capability, but PLRS/PJH satisfies digital communications requirements and GPS does not.

(3) Since all subsystems are vehicular mounted, weight restrictions are not a problem for the FISTV.

(4) PLRS/PJH and NSG is the preferred survey method.

5-9. SOUND/FLASH OBSERVATION SECTION.

a. Survey System Performance (Table 5-14).

(1) Fifth-order survey is the only base case method that satisfies the survey requirement.

(2) The addition of PLRS/PJH with compass significantly increases the SCEP; however, when the PLRS/PJH is combined with the AMD all methods except map spot are within the required SCEP.

(3) The use of GPS with compass does not represent a significant improvement over the PLRS/PJH and compass methods.

(4) The GPS with AMD-3 represents some improvement over the PLRS/PJH and AMD-3 method.

Table 5-14. SCEP values for S/F Obsn Section. OT range 3 km(a)

	HORIZONTAL CONTROL	(CEPm) TRF	AZIMUTH CONTROL	(PEm) TRF	VERTICAL CONTROL	(PEm) TRF	SURVEY (CEPm)
Accuracy Requirements	87.5(b)	-	10.00(b)	-	20.00(b)	-	100
Base Case Methods:							
5th Order	8.1(k)	-	0.4 (k)	-	2.66(k)	-	9
PLRS and Compass	30.0(s)	-	54.15(d)	-	10.00(s)	-	162
2PT LRF w/GLLD and Compass	30.9(g)	-	54.15(d)	-	10.00(e)	-	162
2PT LRF w/HHLR-2 and Compass	82.9(g)	-	54.15(d)	-	10.00(e)	-	191
Polar Plot w/HHLR-1/Compass	134.2(h)	-	54.15(d)	-	10.00(e)	-	225
Polar Plot w/HHLR-2/Compass	143.9(h)	-	54.15(d)	-	10.00(e)	-	232
Map Spot and Compass	150.0(i)	-	54.15(d)	-	10.00(e)	-	236
Resection w/NSG	187.3(c)	-	54.15(d)	-	10.00(e)	-	264
Alternate Methods:							
GPS and AMD-3	8.5(t)	-	1.35(f)	-	10.00(t)	-	18
Resection w/AMD-3	20.7(c)	-	1.35(f)	-	10.00(e)	-	26
Polar Plot w/HHLR-1/AMD-3	26.0(h)	-	1.35(f)	-	10.00(e)	-	31
PJH and AMD-3	30.0(s)	-	1.35(f)	-	10.00(s)	-	34
2PF LRF w/HHLP-1 and AMD-3	30.9(g)	-	1.35(f)	-	10.00(e)	-	35
Polar Plot w/HHLR-2/AMD-3	60.5(h)	-	1.35(f)	-	10.00(e)	-	63
2PF LRF w/HHLR-2 and AMD-3	82.9(g)	-	1.35(f)	-	10.00(e)	-	85
Map Spot and AMD-3	[illegible]0(i)	-	1.35(d)	-	10.00(s)	-	151
GPS and Compass	8.5(t)	-	54.15(d)	-	10.00(t)	-	154
PJH and Compass	30.0(s)	-	54.15(d)	-	10.00(s)	-	162

b. Effectiveness conclusions. FRCEP and ORCEP values are listed at tables 5-15 and 5-16 respectively. EFC values, at table 5-17, are shown for four survey methods and for two contingencies where components of the system are not available.

Table 5-15. FRCEP values for various survey methods and equipments. OT range 3 km, S/F observation section

SELF-LOCATION METHOD	EQUIPMENT HHLR-1 AMD-3	HHLR-1 COMPASS	HHLR-2 AMD-3	HHLR-2 COMPASS
Resection	91.4-110.9	288.3-295.3	121.8-137.2	297.5-303.9
2PT LRF	93.9-112.9	218.8-227.7	147.0-159.9	244.4-252.2
Polar Plot	93.9-113.8	254.5-262.1	134.7-148.5	270.4-277.7
Map Spot	174.7-185.9	260.9-268.4	193.0-203.3	274.5-281.6
5th Order*	89.0-109.1		120.2-135.6	
PLRS (or PJH)	94.1-113.4	219.1-228.0	123.8-138.9	233.5-241.7
GPS	89.7-109.7	216.7-225.5	122.2-137.8	231.3-239.9

*Azimuth was provided by survey.

Table 5-16. ORCEP values for various survey methods and equipments. OT range 3 km, S/F observation section

SELF-LOCATION METHOD	EQUIPMENT HHLR-1 AMD-3	HHLR-1 COMPASS	HHLR-2 AMD-3	HHLR-2 COMPASS
Resection	47.0-47.0	49.7-49.8	124.8-124.8	125.9-125.9
2PT LRF	46.7-46.8	49.0-49.1	125.2-125.2	125.5-125.5
Polar Plot	47.1-47.2	49.3-49.4	125.8-125.9	125.3-125.4
Map Spot	47.9-48.1	49.6-49.7	124.7-124.8	126.8-126.9
5th Order*	46.9-47.0		124.5-124.5	
PLRS (or PJH)	46.8-46.8	49.3-49.4	125.2-125.3	125.6-125.6
GPS	47.4-47.5	49.2-49.2	123.4-123.4	127.0-127.0

*Azimuth was provided by survey.

(1) The fifth order survey method yields the best FRCEP EFC.

(2) When the AMD-3 is added for orientation, either PLRS/PJH or GPS shown an FRCEP EFC almost as good as fifth order survey.

(3) Given a compass for orientation, the PLRS/PJH FRCEP suffers a drastic loss--to the point that first round FFE is not a viable option when one considers the increase shown in the PLRS ORCEP EFC.

Table 5-17. EFC for average FRCEP/ORCEP values for various survey methods. OT range 3 km, S/F observation section

CASE I: Primary source operational

Survey Method	FRCEP	FRCEP EFC	ORCEP	ORCEP EFC
5th Order	113	.29	86	.41
PLRS and Compass	231	.09	87	.40
PLRS and AMD-3	118	.26	86	.41
GPS and AMD-3	115	.28	86	.41

CASE II: Primary source not operational and AMD-3 not available.

#Ref Pts Available	Survey Method	FRCEP FRCEP	EFC	ORCEP ORCEP	EFC
2	2PT LRF	236	.08	87	.40
1	Polar Plot	266	.07	87	.40
Ø	Map Spot	271	.06	88	.40

CASE III: Primary source not operational and AMD-3 available.

#Ref Pts Available	Survey Method	FRCEP FRCEP	EFC	ORCEP ORCEP	EFC
2	Resection	115	.28	86	.41
1	Polar Plot	123	.25	86	.41
Ø	Map Spot	189	.12	86	.41

(4) In Case II, without AMD, hasty methods yield low FRCEP EFC's--and the results are the same as in (3) above.

(5) In Case III, given the AMD-3 and external reference points, the FRCEP EFC's for hasty methods are equivalent to primary source FRCEP EFC's (fifth order, PLRS/PJH, GPS). The AMD also offers some improvement when no reference points are available and map spot must be used.

c. Subanalysis Conclusions.

(1) PLRS/PJH and the NSG provide adequate survey capability with no dependence upon external reference points or survey parties.

(2) GPS offers a slight improvement to the survey capability, but PLRS/PJH offers a digital communications capability and GPS does not.

(3) PLRS/PJH and AMD is the preferred survey method.

5-10. SOUND RANGING.

a. Microphone Positioning Error. The general methodology for determining SCEP at Appendix B is not applicable for determining the impact of survey error on sound ranging target locations. A special analysis, conducted with the assistance of the Target Acquisition Specialist Branch, Target Acquisition Department, was utilized to evaluate random microphone positioning errors. The necessary background discussion and analysis are described below.

(1) Sound ranging locates an enemy firing position by sensing times of arrival of the acoustic signal at the various microphone locations and performing a least-squares solution for the location of the acoustic source. The data used consists of the times of arrival of the sound wave at each microphone, the assumed microphone locations, and meteorological data used to refine the estimated velocity of sound from source to microphone. If none of these are in error, the least-squares solution will give the correct location, subject to rounding errors, etc. When errors in any of the above quantities are present, the accuracy of the acoustic source location is degraded.

(2) The accurate horizontal positioning of the individual microphones is known from Army laboratory sources to be extremely critical. Sound wave times of arrival are worthless if locations of arrival are unknown. In relation, vertical positioning is relatively insignificant and was ignored in this analysis. Since the sound ranging computer, the OL-274, uses "differences" in acoustic times of arrival to perform a least-squares solution, this analysis focused on the system's sensitivity to random microphone-to-microphone error -- that error which is independent from one microphone to the next. Small systematic positioning errors directly bias the sound ranging solution, however, their contribution to the total target location error is relatively small, and for the purposes of simplicity in this analysis, are ignored.

(3) The nominal sound base geometry assumed for this analysis is shown at figure 5-4. The width of the sound base is slightly wider than normal (5.9 second sub-base versus a 4 to 5 second sub-base). A narrower base would tend to magnify the impact of random microphone-to-microphone errors. Four enemy firing positions (targets 202, 203, 402, 403, figure 5-4) were selected to bound comparisons. These locations include locations at 20 km range in the center of the base and targets on the flanks where sensitivity to random errors is greatest.

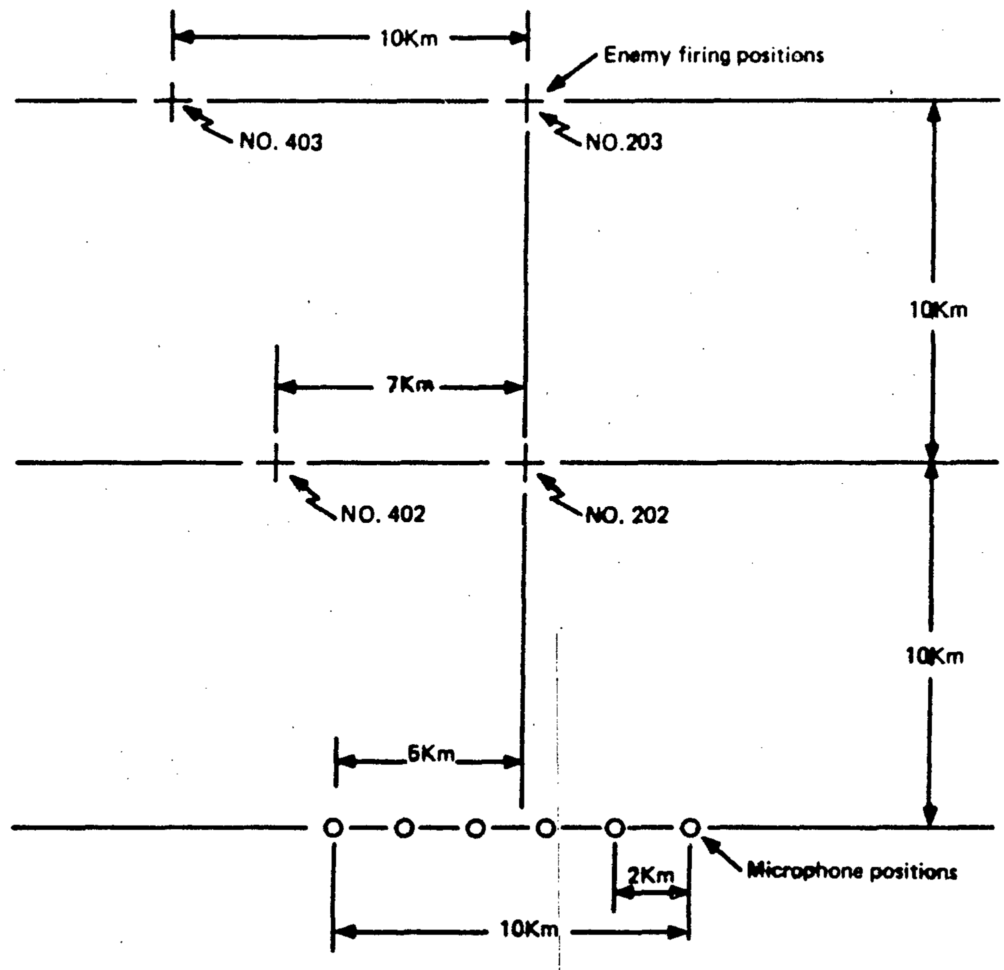


Figure 5-4. Assumed sound base geometry

(4) A Monte Carlo methodology was used to estimate target location accuracies given random microphone-to-microphone positioning accuracies of 1, 2, 6, and 10 meters CEP. All other error factors, such as terrain anomalities, which could contribute to the total sound ranging error were ignored. Standard weather conditions and perfect knowledge of the speed of sound was assumed. All resultant target location accuracies were strictly attributable to the microphone positioning errors. In short, the resultant target location accuracies are sound ranging SCEP's.

(5) Each Monte Carlo repetition consisted of the following procedure:

--Microphone positioning errors were determined by sampling from the appropriate circular normal distribution. An independent sampling was performed for each of the sound bases' six microphones. "Actual" microphone positions were computed using the "intended" microphone positions and the corresponding sampled errors.

-- Times of arrival were computed for an acoustic signal from an "actual" target position to each of the six "actual" microphone positions.

-- The computed times of arrival and the "intended" microphone positions were input to the OL-274 sound ranging computer which output an "estimated" target location.

-- The "estimated" target location was compared with the "actual" target position to determine a sample target location error attributable to a sample set of microphone positions.

(6) Twenty Monte Carlos were accomplished for each combination of nominal target positions (202, 203, 402, 403) and random positioning accuracy (1, 2, 6, 10 meters CEP). Individual target location errors were aggregated for each of the 16 Monte Carlo sets by computing a 1 sigma radial error and converting this error to a CEP. The results are presented at table 5-18.

Table 5-18. Sound ranging target location errors as a function of random microphone-to-microphone positioning accuracy

	RANDOM MIC-TO-MIC POSITIONING ACCURACY (meters-CEP)				
TARGET	1	2	6	8*	10
202	10	12	52	69	87
203	20	45	134	184	232
402	25	62	188	259	330
403	64	121	398	524	650

*Interpolated data

b. Survey System Performance. The preceeding analysis leaves no doubt that random microphone positioning errors can contribute significantly to target location errors. This factor is critical when considering candidate survey systems for sound ranging. The candidate systems include conventional survey, PLRS, GPS and PADS.

(1) The conventional survey party has conducted sound base surveys with excellent results for many years. Tests have shown their accuracy to be approximately 3 meters CEP. Closing criteria is not more than one meter radial error per three thousand meters traveled. Since the usual distance between adjacent microphones is 1350 meters, the party has no difficulty in meeting the requirement. The survey response time is slow, however, and significantly delays sound ranging operations.

(2) The PLRS can be eliminated from further consideration because of its relatively large positioning errors and inconsistency in error distribution.

(3) The GPS appears attractive in that it would be a relatively low cost method of surveying the base. The system cannot, however, achieve the required relative accuracy between microphones because the satellites are constantly moving and cause random errors as the user unit moves down the microphone base.

(4) Formal test data on the PADS capability to satisfy the sound ranging requirement is not available at this time. Informal evaluations conducted by the Counterfire Department, USAFAS, indicate that PADS is satisfactory when a three-minute versus the standard ten-minute update is used. The department plans to conduct additional testing to validate this procedure.

(5) The Australian Army has conducted tests to evaluate use of PADS for sound base survey. A three-minute update was used. Preliminary data indicates that PADS will meet the .9 meter CEP standard.

c. Effectiveness. Additional analysis was conducted to determine the impact of relaxing the accuracy standard for sound ranging from the current .9 meter CEP (rounded to 1 meter) to 8 meters CEP, typical of GPS performance. The results, shown at table 5-19, presents the rounds required to achieve equal effects for the four targets used in the positioning area analysis, given 1 and 8 meter CEP's and an additional error of 75 meters CEP to account for weather and terrain anomalies. The analysis shows that the accuracy standard should not be relaxed.

Table 5-19. Effectiveness comparison for microphone positioning errors

TARGET NO.	MICROPHONE EMPLACEMENT ERROR (CEPm)	ERROR DUE TO MIC EMPL ERROR (CEPm)	TOTAL LOCATION ERROR (CEPm)	ROUNDS REQUIRED FOR EQUAL EFFECTS
202	.9	10	76	28
	8.0	69	102	33
203	.9	20	78	28
	8.0	184	199	72
402	.9	25	79	28
	8.0	259	270	128
403	.9	64	99	32
	8.0	524	529	128

d. Conclusion. PADS is the preferred survey method, however, additional testing is required to validate the three-minute update procedure.

5-11. REMOTELY PILOTED VEHICLE (RPV).

a. Survey System Performance (Table 5-20).

Table 5-20. SCEP values for RPV. Range to target 30 km (bb)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEø) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	21.00(b)	-	0.50(b)	-	10.00(b)	-	32
Base Case Methods:							
4th Order w/ASTRO AZ	5.73(y)	-	0.06(aa)	.15(cc)	1.88(y)	-	9
4th Order w/SIAGL AZ	5.73(y)	-	0.12(z)	.15(cc)	1.88(y)	-	9
4th Order w/PADS AZ	5.73(y)	-	0.40(y)	.15(cc)	1.88(y)	-	15
5th Order	8.10(k)	-	0.40(k)	.15(cc)	2.66(k)	-	17
Resection w/A.C.	28.90(c)	-	6.00(q)	.15(cc)	10.00(e)	-	176
PLRS and A.C.	30.00(s)	-	6.00(q)	.15(cc)	10.00(s)	-	177
Map Spot and A.C.	150.00(i)	-	6.00(q)	.15(cc)	10.00(e)	-	250
Alternate Methods:							
GPS and AMD-1	8.50(t)	-	0.34(w)	-	10.00(+)	-	23
GPS and AMD-2	8.50(t)	-	0.67(r)	-	10.00(+)	-	31
Resection w/AMD-2	20.22(c)	-	0.67(r)	.15(cc)	10.00(e)	-	36
PJH and AMD-1	30.50(s)	-	0.34(w	.15(cc)	10.00(s)	-	37
PJH and AMD-2	30.00(s)	-	0.67(r)	.15(cc)	10.00(s)	-	42
Map Spot and AMD-2	150.00(i)	-	0.67(r)	.15(cc)	10.00(e)	-	153

(1) All fourth and fifth order systems satisfy the requirement.

(2) Those systems that utilize the aiming circle for directional control do not satisfy the requirement.

(3) The use of GPS in conjunction with the AMD-2 will satisfy the survey requirement. If an AMD-1 is used, the SCEP could be reduced from 31 to 23 which is close to fourth order PADS results and meets the survey requirement.

b. Effectiveness Conclusions.

(1) There is practically no loss in EFC (0-1 percent) when fourth-order survey methods (with astro or SIAGL azimuth) are used.

(2) There is a slight increase in loss of EFC (1-4 percent) when PADS is used for azimuthal control.

(3) The loss in EFC resulting from use of hasty methods (50-90 percent) is unacceptable. These losses are attributable to the inaccuracy of the aiming circle, coupled with the long ranges at which the RPV acquires targets.

(4) The GPS with AMD-2, the only alternative system that meets SCEP requirements, causes a 3-10 percent loss in EFC.

(5) Use of the AMD-2 improves EFC considerably for all other survey methods. Only map spot remains impractical.

(6) The AMD-1 was considered for sensitivity purposes. The GPS with AMD-1 results in a 1-6 percent loss in EFC and the PLRS/PJH with AMD-1 has a potential for only a 2-8 percent loss in EFC.

c. Subanalysis Conclusions.

(1) All fourth and fifth order survey methods result in minimum loss in EFC.

(2) The GPS in conjunction with the AMD can relieve the RPV of external dependence on fourth or fifth order survey with a small and reasonable loss in EFC.

5-12. MOVING TARGET LOCATING RADAR (MTLR) (Table 5-21).

Table 5-21. SCEP values for MTLR. Range to target 10 km (jj)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEm) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	43.75(b)	-	3.00(b)	-	30.00(b)	-	75
Base Case Methods:							
5th Order	8.10(k)	-	0.40(k)	.6(v)	2.66(k)	-	13
Resection w/A.C.	28.90(c)	-	6.00(q)	.6(v)	10.00(e)	-	73
PLRS and A.C.	30.00(s)	-	6.00(q)	.6(v)	10.00(s)	-	74
Map Spot and A.C.	150.00(i)	-	6.00(q)	.6(v)	10.00(e)	-	166
Alternate Methods:							
GPS and AMD-3	8.50(t)	-	1.35(f)	.6(v)	10.00(t)	-	26
Resection w/AMD-3	20.22(cc)	-	1.35(f)	.6(v)	10.00(e)	-	32
PJH and AMD-3	30.00(s)	-	1.35(f)	.6(v)	10.00(s)	-	39
Map Spot and AMD-3	150.00(i)	-	1.35(f)	.6(v)	10.00(e)	-	152

(1) All base case systems except map spot meet the required SCEP with fifth order survey yielding the lowest value.

(2) Responsive survey can be provided with either PLRS/PJH or GPS used with the AMD-3. No dependence on external survey or external reference points are required.

b. Effectiveness discussion.

(1) The general approach to determine effectiveness used for other sensors could not be used for the MTLR. The methodology assumes a 50 meter CEP target location error (TLE) for most other sensors when computing the SCEP EFC values (see paragraph h, Appendix D for detail). These other sensors are relatively accurate and the SCEP easily becomes the major portion of the total TLE and is therefore critical. This is not the case with the MTLR because MTLR acquisitions are moving targets and the error associated with prediction and timing routines degrade the total target location accuracy to the point that SCEP's significance is lost. This rationale is described in the example which follows:

(2) The following assumptions were used to illustrate the impact of SCEP error on MTLR operations.

(a) A moving target, nominal rate of travel 10 km per hour, is detected by the MTLR. The current location of the target, time of detection, estimated direction and rate of travel are reported to higher headquarters.

(b) The direction of travel is predicted to an accuracy of 100 mils, 1 standard deviation and the rate of travel is predicted to an accuracy of 2 km/hour, 1 standard deviation. Field artillery fire is delivered six minutes after the target report is submitted to FDC and the six-minute time lag is known precisely.

(3) The CEP caused by prediction and timing errors alone may be approximated as follows:

2000 -- rate of travel prediction error (std dev in m/hour)
x.10 -- time lag since last report (hours)
= 200 -- distance error (std dev in m)

100 -- direction prediction error (std dev in mils)
x 10 -- nominal rate of travel (km per hour)
x 10 -- time lag since last report (hours)
= 100 -- cross distance error (std dev in m)

The above component errors result in a 177 m CEP.

(4) The following examples illustrate how large target location errors (TLE), such as the example above, desensitize SCEP relative contribution to MTLR TLE as compared to more typical FA target location errors, such as 50 m CEP.

TLE w/o SCEP (m)	SCEP (m)	TLE w/SCEP(m)	TLE Increase(%)
177	20	178.1	0.6
177	40	181.5	2.5
177	60	186.9	5.6
50	20	53.9	7.7
50	40	64.0	28.1
50	60	78.1	56.2

(5) No effort was made to generate additional EFC curves for the MTLR because such curves would grossly over-estimate SCEP impact on EFC for the MTLR. The objective of the subanalysis is simply to select a reasonably accurate and responsive survey system.

c. Subanalysis Conclusions.

(1) The PLRS/PJH used in conjunction with the AMD-3 provides sufficient accuracy with excellent responsiveness.

(2) The GPS, in conjunction with the AMD-3, provides a slight reduction in target location error. GPS responsiveness is well within the requirement.

(3) The GPS with AMD-3 is the preferred survey system for the MTLR.

5-13. MORTAR LOCATING RADAR (MLR).

a. Survey System Performance (Table 5-22).

Table 5-22. SCEP values for MLR. Range to target 15 km (u)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEm) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	10.00(b)	-	0.30(b)	-	10.00(b)	-	31
Base Case Methods:							
5th Order	8.10(k)	-	0.40(k)	.6(v)	2.66(k)	-	18
Resection w/A.C.	28.90(c)	-	6.00(q)	.6(v)	10.00(e)	-	108
PLRS and A.C.	30.00(s)	-	6.00(q)	.6(v)	10.00(s)	-	109
Map Spot and A.C.	150.00(i)	-	6.00(q)	.6(v)	10.00(e)	-	188
Alternate Methods:							
GPS and SIAGL	8.50(t)		0.12(z)	.6(v)	10.00(t)	-	21
GPS and AMD-2	8.50(t)	-	0.67(r)	.6(v)	10.00(+)	-	37
Resection w/AMD-2	20.22(cc)	-	0.67(r)	.6(v)	10.00(e)	-	42
PJH and AMD-2	30.00(s)	-	0.67(r)	.6(v)	10.00(s)	-	47
Map Spot and AMD-2	150.00(i)	-	0.67(r)	.6(v)	10.00(e)	-	155

(1) Only the fifth order survey system among the base case systems will satisfy the requirement. Base case methods other than fifth order result in poor SCEP's largely due to aiming circle orientation errors.

(2) The only listed alternative system to meet the SCEP requirement is GPS with a SIAGL azimuth. It can be assumed, based on an evaluation of the data, that GPS with an AMD-1 would also satisfy the requirement.

b. Effectiveness Conclusions.

(1) The loss in EFC due to use of the fifth order system is small (1-3 percent). Other base case systems, which utilize the aiming circle for orientation, result in impractical losses in EFC (25-80 percent).

(2) The GPS, used in conjunction with the SIAGL or AMD-1, results in a relatively small loss in EFC (1-6 percent).

(3) All other alternatives result in a minimum of 5-15 percent loss in EFC.

c. Subanalysis Conclusions.

(1) Fifth order survey is the only base case survey system to meet the required SCEP (table 5-20).

(2) The GPS, with the AMD-1, is the only alternative system which can satisfy both the SCEP and response time requirements (20 minutes). The SIAGL response time (45 minutes) is not adequate. The use of GPS and the AMD-1 offers improved responsiveness and lower cost, compared to PADS.

(3) The azimuth transfer error is a significant factor in SCEP calculations. This problem should be investigated further to determine if the assumptions in this study are correct, and/or if the error can be reduced or eliminated.

(4) PADS is the near term system, followed by GPS and the AMD in the 1990 time frame.

5-14. WEAPONS LOCATING RADAR (WLR).

a. Survey System Performance (Table 5-23).

Table 5-23. SCEP values for WLR. Range to target 30 km (x)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEm) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	10.00(b)	-	0.15(b)	-	3.00(b)	-	15
Base Case Methods:							
PADS 3-Min Update w/ASTRO AZ	3.00(kk)	-	0.06(aa)	.6(v)	10.00(t)	-	21
4th Order w/ASTRO AZ (3)	5.73(y)	-	0.06(aa)	.6(v)	1.88(y)	-	21
4th Order w/SIAGL AZ	5.73(y)	-	0.12(z)	.6(v)	1.88(y)	-	22
4th Order w/PADS AZ	5.73(y)	-	0.40(v)	.6(v)	1.88(y)	-	24
Resection w/A.C.	28.90(c)	-	6.00(q)	.6(v)	10.00(e)	-	187
PLRS and A.C.	30.00(s)	-	6.00(q)	.6(v)	10.00(s)	-	187
Map Spot and A.C.	150.00(i)	-	6.00(q)	.6(v)	10.00(e)	-	254
Alternate Methods:							
GPS and SIAGL	8.50(t)	-	0.12(z)	.6(v)	10.00(t)	-	21
GPS and AMD-1	8.50(+)	-	0.34(w)	.6(v)	10.00(+)	-	43
Resection w/AMD-1	20.20(c)	-	0.34(w)	.6(v)	10.00(e)	-	47
PJH and AMD-1	30.00(s)	-	0.34(w)	.6(v)	10.00(s)	-	52

(1) None of the base case survey methods meet the required SCEP. It should be noted however, that the fourth order systems exceeded the required SCEP largely due to the azimuth transfer error and the long radar-to-target range. Other base case systems exceed the required SCEP largely due to aiming circle orientation errors.

(2) As an excursion, an additional SCEP was computed to represent PADS positioning with 3-minute updates and orientation with an astronomic azimuth. This is the most accurate possible survey method for all practical purposes, yet the resultant SCEP was only improved to 18 meters because of the large azimuth transfer error.

(3) The only alternative system which is close to satisfying the SCEP requirement is GPS and SIAGL (21 m versus 15 m required).

(4) The azimuth transfer error is a significant factor in achieving the required SCEP and requires further investigation. A similar problem was noted in the MLR discussion.

(5) The vertical control error is also a significant factor for the WLR (See paragraph B-1a(3)). For example, given an ascent angle of 300ḿ on an enemy projectile, the vertical control probable of 10 m PE for the GPS will cause a radar ranging error of 33 meters PE, as compared to an error of 9.0 m for the PADS vertical control error of 1.88 m PE.

b. Effectiveness Conclusions.

(1) The loss in EFC with fourth order systems and the PADS three-minute update is small. The PADS horizontal and vertical data, used with an astronomic or SIAGL azimuth results in a 1-4 percent loss in EFC. Substitution of the PADS azimuth increases the EFC loss slightly to 2-6 percent. Hasty methods which utilize the aiming circle for orientation result in impractical losses in EFC (50-90 percent).

(2) The use of GPS in conjunction with SIAGL, results in a 1-4 percent loss in EFC. Other alternative systems result in EFC losses of 6-24 percent.

c. Subanalysis Conclusions.

(1) The required SCEP cannot be achieved by any of the systems.

(2) Azimuth transfer error degrades all alternative SCEP's and requires further investigation. This subject is discussed further in Chapter 6 as an uncertainty.

(3) PADS is the obvious choice for a near term system even though it does not quite satisfy the SCEP requirement. The small differences in SCEP obtained with the various azimuth alternatives and the three-minute update are not significant and degrade responsiveness.

(4) GPS and SIAGL is a logical cost effective and responsive alternative, particularly if the GPS vertical control accuracy proves to be better than required during DT/OT. The GPS and AMD-1 alternative is also viable if the azimuth transfer problem is solved.

5-15. METEOROLOGICAL DATA SYSTEM (MDS)

a. Survey System Performance.

(1) This subanalysis provides a unique SCEP methodology for the MDS. The use of simplifying assumptions and a worst-case approach are sufficient for a practical comparison of alternative MDS survey methods.

(2) It is necessary to understand the error contributions of meteorological (MET) effects in order to understand the nature of "on-target" error introduced by positioning and orientation errors at the MDS. Given "standard" MET conditions, accurate firing data may be determined to deliver artillery ammunition onto the target. As MET conditions vary from "standard" appropriate adjustments to the firing data are required to improve delivery accuracy. These adjustments are called MET corrections. The accuracy of these corrections are naturally dependent upon the accuracy of MET data. MET data errors may be categorized as follows:

(a) Spatial considerations. Spatial error is caused by variability of meteorological conditions from one location to the next. MET data is measured along the MET balloon's ascent path. MET corrections are then applied for an artillery trajectory which passes through a different atmosphere with its own MET conditions.

(b) Staleness of MET data. Staleness error is caused by variability of MET conditions from one time to the next. Measuring, processing, and distributing MET data is time-consuming. MET conditions are measured during the MET balloon's ascent; corrections are then applied at a later time when meteorological conditions may have changed.

(c) Instrument errors. Instrument errors are simply the errors inherent in devices which actually measure MET conditions.

(d) Procedural errors. Procedural errors are errors such as round-off and approximation techniques.

(3) MDS positioning error contributes only to spatial error. The distances, however, from a MET balloon's ascent path to artillery trajectories are so large that any reduction in spatial error due to accurate positioning of the MDS is considered insignificant. Therefore, positioning errors are eliminated from MDS SCEP calculations, leaving only orientation errors to consider.

(4) The two general techniques used in the MDS are navigation aids NAVAIDS) and radio direction finding (RDF). Only the RDF technique requires orientation of the antenna. RDF orientation errors contribute to the "on target" errors in the procedural error category by skewing the ballistic wind solution. An orientation error directly degrades the ballistic wind estimate causing error in compensation for range and cross-winds on subsequent fire missions. These errors are used as an MDS SCEP.

(5) The following assumptions are used as a basis for computing a worst case example of a MDS SCEP.

(a) The MDS RDF antenna is nominally oriented to the north (6400 ₥) with M2A2 aiming circle accuracy (6 ₥ PE/8.9 mils standard deviation SD). The ballistic wind speed is extremely high, 60 knots, and the ballistic wind direction is 800 mils.

(b) A subsequen fire mission is conducted with the M109A3 howitzer firing M483A1 ammunition. The range is 20 km and the direction of fire is 6400 mils.

(6) The one sigma RDF orientation error of 8.9 mils directly translates into a "should have" reported ballistic wind direction with a one sigma variation from 791.1 ₥ to 808.9 m. Sixty knot winds affect an artillery trajectory fired at an azimuth of 6400 ₥ as follows:

Wind Direction (₥)	Range Wind (knots)	Cross Range Wind (knots)
791.1	42.80	42.05
800.0	42.43	42.43
808.9	42.05	42.80

The above data shows an approximate 0.38 knot SD in range and/or cross-range wind speed estimates attributable solely to RDF orientation error.

(7) Unit correction factors for range-wind and cross-wind compensation extracted from Table F, FT 155 AN-1, C-2 (Prov), are as follows:

Azimuth correction -- 0.73 ₥ per knot of cross-range wind
Range correction -- 18.2 m per knot of range wind

(8) The error in compensation for cross and range winds is computed as follows:

0.38 --	range wind error (SD in knots)
x 18.20	range wind distance corrections per knot (m)
6.92	total range wind corrections (SD in m)

0.38	cross-range wind error (SD in knots)
x 0.73	cross-range wind azimuth correction per knot (₥)
x 20.00	gun-target range (km)
5.55	total cross-range wind correction (SD in m)

The combined effect of these corrections is 7.3 m, which is the MDS SCEP.

b. Effectiveness Conclusions.

(1) The current method of RDF antenna orientation is the ML 474/GM Theodolite with a floating magnetic needle. This method is assumed to be as accurate as aiming circle orientation.

(2) Loss of EFC attributable to the current means of MDS RDF antenna orientation is assumed negligible for the following reasons:

(a) The 7.3 m SCEP derived in the example (para 5-15a) was an extreme case. The typical SCEP would be much less.

(b) Table 5-1 shows less than a one-percent loss in EFC caused by a 7.3 m SCEP when applied to the "standard" artillery mission. The EFC would be even less than the one-percent value because the impact of SCEP on 20 km range is less than the "standard" mission range of 12 km.

c. Subanalysis Conclusions.

(1) Positioning accuracy is not critical for the MDS. The PLRS/PJH system is recommended to satisfy positioning, as well as digital communications requirements.

(2) The current method of MDS RDF antenna orientation is acceptable and should be retained.

5-16. SELF-PROPELLED HOWITZER BATTERY (SP HOW BTRY).

a. Survey System Performance (Table 5-24).

Table 5-24. SCEP values for SP HOW BTRY. Gun-target range 12 km (j)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEm) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	17.50(b)	-	0.30(b)	-	10.00(b)	-	24
Base Case Methods:							
5th Order	8.10(k)	10(l)	0.40(k)	1.20(m)	2.66(m)	1.00(n)	22
Resection w/A.C.	28.90(c)	10(l)	6.00(q)	1.20(m)	10.00(e)	1.00(n)	85
PLRS and A.C.	30.00(s)	10(l)	6.00(q)	1.20(m)	10.00(s)	1.00(n)	86
Map Spot and A.C.	150.00(i)	10(l)	6.00(q)	1.20(m)	10.00(e)	1.00(n)	175
Alternate Methods:							
GPS (on How) and AGPS AZ	8.50(ff)	-	0.67(ff)	-	10.00(ff)	-	21
AGPS w/5th Order Init	8.10(o)	15(p)	-	0.67(p)	2.66(o)	3.37(p)	21
AGPS w/GPS Init	8.50(o)	15(p)	-	0.67(p)	10.00(o)	3.37(p)	26
PJH (on How) w/AGPS AZ.	30.00(ff)	-	0.67(ff)	-	10.00(ff)	-	36
AGPS w/PJH Init	30.00(o)	15(p)	-	0.67(p)	10.00(p)	3.37(p)	39

(1) The fifth order system is the only base case system to satisfy the requirement. Other base case systems fail to meet the requirement largely due to aiming circle orientation errors.

(2) The AGPS improves responsiveness of survey and positioning flexibility with no loss in survey accuracy.

(3) The AGPS, initialized with on-board GPS, is as accurate as fifth-order survey. GPS initialization, external to the howitzer, is less accurate than on-board initialization and slightly exceeds the requirement.

(4) Survey responsiveness could be improved with PJH initialization of the AGPS, however the resultant SCEP does not meet the requirement.

b. Effectiveness Conclusions.

(1) The only base case system that satisfies the requirement is fifth order survey. Other hasty techniques which utilize the aiming circle for orientation result in impractical losses in EFC (20-50 percent) when computed to the 1-5 percent loss with fifth order survey.

(2) The AGPS using either fifth order initialization or on-board GPS for initialization results in a small loss in EFC (1-5 percent).

(3) The use of GPS initialization external to the howitzer increases the EFC loss to approximately 2-8 percent.

(4) Use of the PJH for either on-board or external initialization further increases the loss in EFC to approximately 5-15 percent.

c. A trade-off consideration. The key features of alternative methods for obtaining initialization data for the AGPS are summarized at table 5-25. These alternatives are:

Table 5-25. Key features of alternative methods for obtaining initialization data for the AGPS

	CURRENT	PLT-LEVEL INITIALIZATION	ON-BOARD INITIALIZATION	
	PADS	GPS	GPS	PJH
Relative Loss in EFC	1-5%	2-8%	1-5%	5-15%
Response Time at Firing Point	-	-	5.5 min	8 sec to 3 min
Initialization External to Platoon Required	Yes	No	No	No
Initialization External to Howitzer Required	Yes	Yes	No	No
On-Board Space Available	NA	NA	?	Yes
Communications Capability	No	No	No	Yes

(a) The current PADS system authorized at battalion level. Three sets per battalion are required for 3 x 8 cannon battalions.

(b) GPS User Units authorized at firing platoon headquarters (3 x 8), six units per battalion are required.

(c) GPS or PJH User Units mounted on-board the individual howitzers. Twenty-four user units per battalion are required.

(2) The use of PJH in conjunction with the AGPS is not preferred as the survey system due to the significant loss in EFC (5-15 percent). The PJH unit is required, however, for digital communications.

(3) The use of "on-board GPS' is not preferred because of cost (24 user units per battalion required) and availability of space on board the howitzer is limited.

(4) The use of GPS to provide positioning data for AGPS initialization instead of PADS has the following advantages/disadvantages:

(a) Increases the loss in EFC slightly.

(b) Increases responsiveness by eliminating the firing platoon's dependence upon external survey. Platoon personnel can operate the user unit and establish points where and when required.

(c) Results in materiel cost and manpower savings in that the three battalion PADS and six personnel can be eliminated.

a. Subanalysis Conclusions.

(1) The use of GPS at the platoon level is the preferred alternative because increased responsiveness at a reduced cost, more than offsets the small degradation in EFC.

(2) The PJH is an alternative system, however, its primary use is digital communications.

(3) A limited quantity of PADS should be available within the division artillery for use in the event of GPS equipment or system failure.

5-17. TOWED HOWITZER BATTERY (Towed HOW BTRY).

a. Survey System Performance (Table 5-26).

Table 5-26. SCEP values for Towed HOW BTRY. Gun-target range 12 km (j)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEm) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	17.50(b)	-	3.0(b)	-	10.00(b)	-	24
Base Case Methods:							
5th Order	8.10(k)	10(1)	0.40(k)	1.2(m)	2.66(m)	1(n)	22
Resection w/A.C.	28.90(c)	10(1)	6.00(q)	1.2(m)	10.00(e)	1(n)	85
PLRS and A.C.	30.00(s)	10(1)	6.00(q)	1.2(m)	10.00(s)	1(n)	86
Map Spot and A.C.	150.00(i)	10(1)	6.00(q)	1.2(m)	10.00(e)	1(n)	175
Alternate Methods:							
GPS and AMD-2	8.50(t)	10(1)	0.67(r)	1.2(m)	10.00(t)	1(n)	29
Resection w/AMD-2	22.22(c)	10(1)	0.67(r)	1.2(m)	10.00(e)	1(n)	34
PJH w/AMD-2	30.00(s)	10(1)	0.67(r)	1.2(m)	10.00(s)	1(n)	41
Map Spot and AMD-2	150.00(1)	10(1)	0.67(r)	1.2(m)	10.00(e)	1(n)	153

(1) The fifth order system is the only base case system to satisfy the required SCEP. Other base case systems fail to meet the requirement largely due to aiming circle orientation errors.

(2) GPS, used in conjunction with the AMD-2, does not meet the required SCEP due to vertical positioning error, but does eliminate dependence upon external survey.

(3) PJH, used in conjunction with the AMD-2, also eliminates dependence upon external survey, but exceeds the required SCEP by a large margin.

(4) Map spot methods are unacceptable.

b. Effectiveness Conclusions.

(1) The loss in EFC with the fifth order system is small (1-5 percent). Hasty techniques employing the aiming circle for orientation result in significant losses in EFC (20-75 percent).

(2) GPS, used in conjunction with the AMD-2, results in a relatively small loss in EFC (3-10 percent).

(3) PJH, used in conjunction with the AMD-2, results in a moderate loss in EFC (6-16 percent).

c. Subanalysis Conclusions.

(1) Fifth order survey (PADS) meets the required SCEP with minimal loss in EFC. It is also the most expensive system in that three PADS and six personnel are required.

(2) The use of GPS and an azimuth measuring device in each firing platoon offers increased responsiveness and a reduction in PADS requirements with a small loss in EFC.

(3) GPS with AMD-2 is the preferred system.

(4) A limited quantity of PADS should be available within the division artillery for use with cannon battalions in the event of GPS equipment or system failure.

5-18. MULTIPLE LAUNCH ROCKET SYSTEM (MLRS).

a. Survey System Performance (Table 5-27).

Table 5-27. SCEP values for MLRS. Launcher target range 30 km (dd)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEm) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	20.00(b)	-	1.00(b)	-	10.00(b)	-	43
Base Case Methods:							
SRP/PDS w/5th Order Init.	8.10(o)	15(p)	-(o)	0.67(p)	2.66(o)	3.37(p)	29
SRP/PDS w/PLRS Init.	30.00(o)	15(p)	-(o)	0.67(p)	10.00(o)	3.37(p)	45
Alternate Methods:							
GPS w/SRP/PDS AZ.	8.50(ff)	-	0.67(ff)	-	10.00(ff)	-	30
SRP/PDS w/GPS Init.	8.50(o)	15(p)	-(o)	0.67(p)	10.00(o)	3.37(p)	35
PJH w/SRP/PDS AZ.	30.00(ff)	-	0.67(ff)	-	10.00(ff)	-	42
SRP/PDS w/PJH Init.	30.00(o)	15(p)	-(o)	0.67(p)	10.00(o)	3.37(p)	45

(1) The SRP/PDS with fifth order initialization is the only base case system that meets the SCEP requirement.

(2) The use of on-board GPS or PJH for position and the SRP/PDS for orientation yields an accuracy almost as good as the fifth order initialization. This improvement is due to the elimination of transfer error, i.e., the position error that accumulates from the initialization point to the firing point. While this method of operation could eliminate the requirement for initialization points, it may not be satisfactory in that the MLRS Self-Propelled Launcher Loader (SPLL) reaction time is 0, meaning that it must be able to fire immediately upon occupation of position.

(3) The SRP/PDS with GPS initialization, though slightly less accurate than fifth order initialization, comfortably met the required SCEP. The PJH initialization resulted in a SCEP slightly greater than the requirement.

b. Effectiveness Methodology. MLRS effectiveness is generally less sensitive to SCEP than tube artillery effectiveness due to the system's large delivery errors and burst patterns. Therefore, an MLRS SCEP EFC curve was generated to more specifically support this subanalysis. The MLRS mission selected for analysis is similar to the "standard" cannon artillery mission described in Appendix F with the following exceptions:

(1) The M109A3/M483 weapon/ammunition combination was replaced by the MLRS with dual purpose ICM warheads.

(2) Delivery errors are representative of a 30 km launcher to target range. Only a single median set of MPI error conditions was assumed.

(3) A 150 meter target radius was used because MLRS is best suited for attack of larger targets.

The number of missiles fired and target type are not described, in order to retain an unclassified discussion. The MLRS SCEP EFC curve is presented in figure 5-5. Relative losses in EFC are derived from this curve.

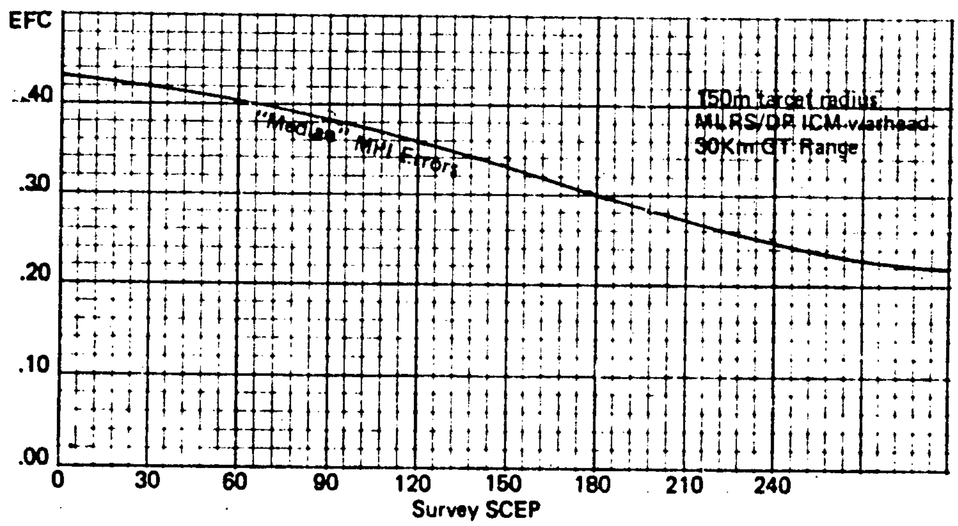


Figure 5-5. MLRS EFC curve.

c. Effectiveness Conclusions.

The various alternative survey methods results show only small differences in EFC losses (0-2 percent).

d. Trade-Off Considerations.

(1) The key features of three major alternative methods, listed below, of augmenting the SRP/PDS in providing position data for the MLRS launcher are at table 5-28.

(a) One PADS system at battery level.

(b) GPS or PLRS User Units authorized at firing platoon headquarters. Three user units are required per firing battery.

(c) GPS or PJH user units mounted on-board the individual launchers. Nine user units are required per battalion.

Table 5-28. Key features of alternative methods for obtaining initialization/calibration data for the SRP/PDS

	CURRENT	PLT-LEVEL AUTHORIZATION		ON-BOARD AUTHORIZATION	
	PADS	GPS	PLRS	GPS	PJH
Relative Loss in EFC	0%	1%	2%	0%	2%
Response Time at Firing Point	-	-	-	5.5 min	8 sec to 3 min
Initialization External to Platoon Required	Yes	No	No	No	No
Initialization External to Launcher Required	Yes	Yes	Yes	No	No
On-Board Space Available	NA	NA	NA	?	Yes
Communications Capability	No	No	Yes	No	Yes
Accuracy Adequate to Establish Calibration Points	Yes	Yes	No	NA	NA

(2) PADS and GPS are equally effective with respect to loss in EFC and capability to establish calibration points.

(3) The on-board alternatives eliminate dependence upon external launcher survey, however, the GPS and PJH response times are inadequate. The zero response time for the launcher will cause GPS and PJH to be used to update the SRP/PDS in the platoon area or reload points, thus eliminating the accuracy advantage of mounting the system on board.

(4) The GPS at platoon level provides the required survey capability at a lower cost than PADS.

a. Subanalysis Conclusions.

(1) PADS is the required near term system.

(2) GPS User Units at platoon level can replace PADS as the long-term survey system at a lower cost.

5-19. LANCE.

a. Survey System Performance (Table 5-29). All survey methods comfortably met the required SCEP.

Table 5-29. SCEP values for LANCE. Launcher target range 60 km (ee)

	HORIZONTAL (CEPm) CONTROL	TRF	AZIMUTH (PEm) CONTROL	TRF	VERTICAL (PEm) CONTROL	TRF	SURVEY (CEPm)
Accuracy Requirements	35.00(b)	-	.3(t)	-	10.00(b)	-	45
Base Case Methods:							
5th Order w/ASTRO AZ.	8.10(gg)	-	.06(aa)	.15(cc)	2.66(gg)	-	14
5th Order w/4th Order AZ.	8.10(gg)	-	.11(hh)	.15(cc)	2.66(gg)	-	16
5th Order w/SIAGL	8.10(gg)	-	.12(z)	.15(cc)	2.66(gg)	-	16
5th Order w/PADS	8.10(gg)	-	.40(y)	.15(cc)	2.66(gg)	-	28
Alternate Methods:							
GPS w/ASTRO AZ.	8.50(t)	-	.06(aa)	.15(cc)	10.00(t)	-	22
GPS w/4th Order AZ.	8.50(t)	-	.11(hh)	.15(cc)	10.00(t)	-	23
GPS w/SIAGL	8.50(t)	-	.12(z)	.15(cc)	10.00(t)	-	23
5th Order w/AMD-1	8.10(gg)	-	.40(y)	.15(cc)	2.66(gg)	-	28
GPS w/AMD-1	8.50(t)	-	.34(w)	.15(cc)	10.00(t)	-	32

b. Effectiveness Conclusions. Lance effectiveness is even less sensitive than MLRS to the SCEP error for the same reasons. Therefore, relative losses in EFC are considered acceptable for all survey methods considered.

c. Subanalysis Conclusions.

(1) The base case PADS alternative provides accurate and timely survey.

(2) The GPS used in conjunction with an orienting device (i.e., SIAGL or AMD-1) can provide equally acceptable survey data at a reduced cost.

CHAPTER 6

FINDINGS

6-1. PURPOSE. The purpose of this chapter is to summarize the results of the analytical analysis, establish the recommended architecture of survey systems from the current time period through 1996 and identify uncertainties associated with the recommended architecture.

6-2. PREFERRED SYSTEMS. The preferred survey system for each user was identified in Chapter 5. User requirements can be categorized into the three categories discussed below:

a. PLRS/PJH and AMD Users. The position and orientation requirements for the following systems can be satisfied by PLRS/PJH and an azimuth measuring device. Variations in the requirement for the azimuth device are noted with appropriate systems.

(1) Ground observers with and without the GLLD.

(2) Fire Support Team Vehicle (FISTV). The AMD is not required because the system includes a north seeking gyro.

(3) Sound/Flash Observation Section.

(4) Meteorological Data System (MDS). The AMD is not required. The orientation system will be the aiming circle.

b. GPS and AMD Users.

(1) Remotely Piloted Vehicle (RPV)

(2) Moving Target Locating Radar (MTLR)

(3) Mortar Locating Radar (MLR)

(4) Self-Propelled Howitzer Battery. An AMD is not required because the Automatic Gun Positioning System (AGPS), which includes an azimuth gyro, is being developed for use on-board each howitzer.

(5) Towed Howitzer Battery.

(6) Multiple Launch Rocket System (MLRS). The AMD is not required because the system includes the Stabilized Reference Platform/Position Determining System (SRP/PDS).

(7) Lance

c. PADS Users.

(1) Sound Ranging

(2) Weapons Locating Radar

6-3 SYSTEM ARCHITECTURE. System architecture is defined through the use of the phase-in Phase-out schedules at figures 6-1 through 6-3. Each figure lists the community of users for the three classes of users, i.e., PLRS/PJH, GPS, and PADS. No attempt is made to establish the number of PADS required for a division area. Additional study of tactical scenarios is required to determine this number. The architecture includes Pershing on the basis of a side analysis that determined that GPS can satisfy the horizontal positioning requirement of 16 M CEP and vertical requirement of 50 M PE for PII at a lower cost than PADS. Azimuth orientation is not required for PII.

6-4. UNCERTAINTIES. The following uncertainties were identified during the analysis.

a. The capability of ground observers who habitually operate dismounted to transport the AMD and a tripod-mounted GVS-5 Laser Rangefinder is in doubt. The written analysis indicates that the additional weight cannot be carried, however, the issue appears worth examining in an operational test (CEP/FDTE) because of the equipment's positive impact on the ability to deliver first round FFE.

b. The lack of test data on PADS accuracies when a three-minute update versus the standard ten-minute update prevented a firm conclusion on the system's capability to satisfy the accuracy standard for relative location of adjacent microphones (0.9 M CEP). Some initial data from PADS testing in Australia became available during the latter part of the study. The data indicates that the three-minute update procedure will satisfy the requirement. The complete test report will be made available to USAFAS at a later date. It appears that Engineer Topographic Laboratory should be tasked to provide assistance in resolving this question and establishing new PADS procedures for sound base survey.

c. The analysis for systems that now or will utilize on-board fire control/positioning systems indicated that serious consideration should be given to installing PLRS/PJH or GPS on board the howitzer/launcher because this solution eliminates the most positioning error. There are technical problems involved with changing the configuration of these on board systems that must be addressed by DARCOM elements.

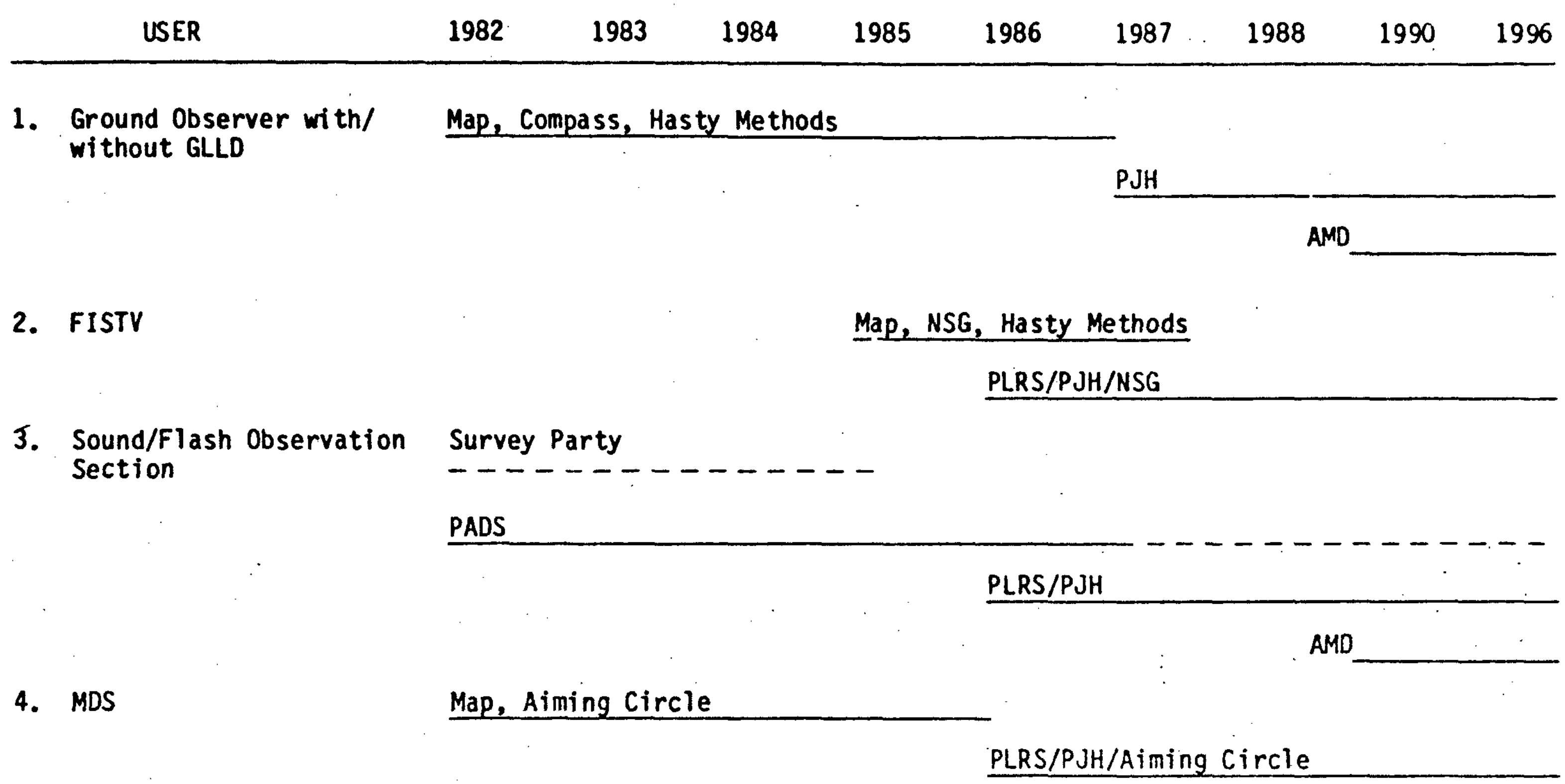
d. The analysis includes assumptions that the AMD PLRS/PJH and GPS will meet performance characteristics stated in requirements documents. The assessment of the risk in meeting these characteristics is as follows:

(1) AMD. The USMC has developed the North Finding Module (NFM) for use with their Modular Universal Laser Equipment (MULE) rangefinder/ designator. The MULE is similar to the FA GLLD. The MULE requirement is to obtain grid azimuth accurate to one mil (rms) in two minutes. The Marines have type classified the NFM; however, the Army has had limited access to development test reports and has not performed a technical assessment to determine if the NFM or modifications thereto could satisfy the requirements stated in the USAFAS Draft ROC for the AMD. The draft ROC includes a requirement to mount the AMD on various equipments such as the FIREFINDER radar and the PM, FIREFINDER has conducted testing with the NFM and modified versions thereof, in an attempt to product improve the radar. Procurement has not proceeded because the program has been unable to resolve wind loading effects on the NFM.

HQ DARCOM is now in the process of identifying the proponent for the AMD. Once the proponent is named, a program can be structured to assess state-of-the-art and the above risks.

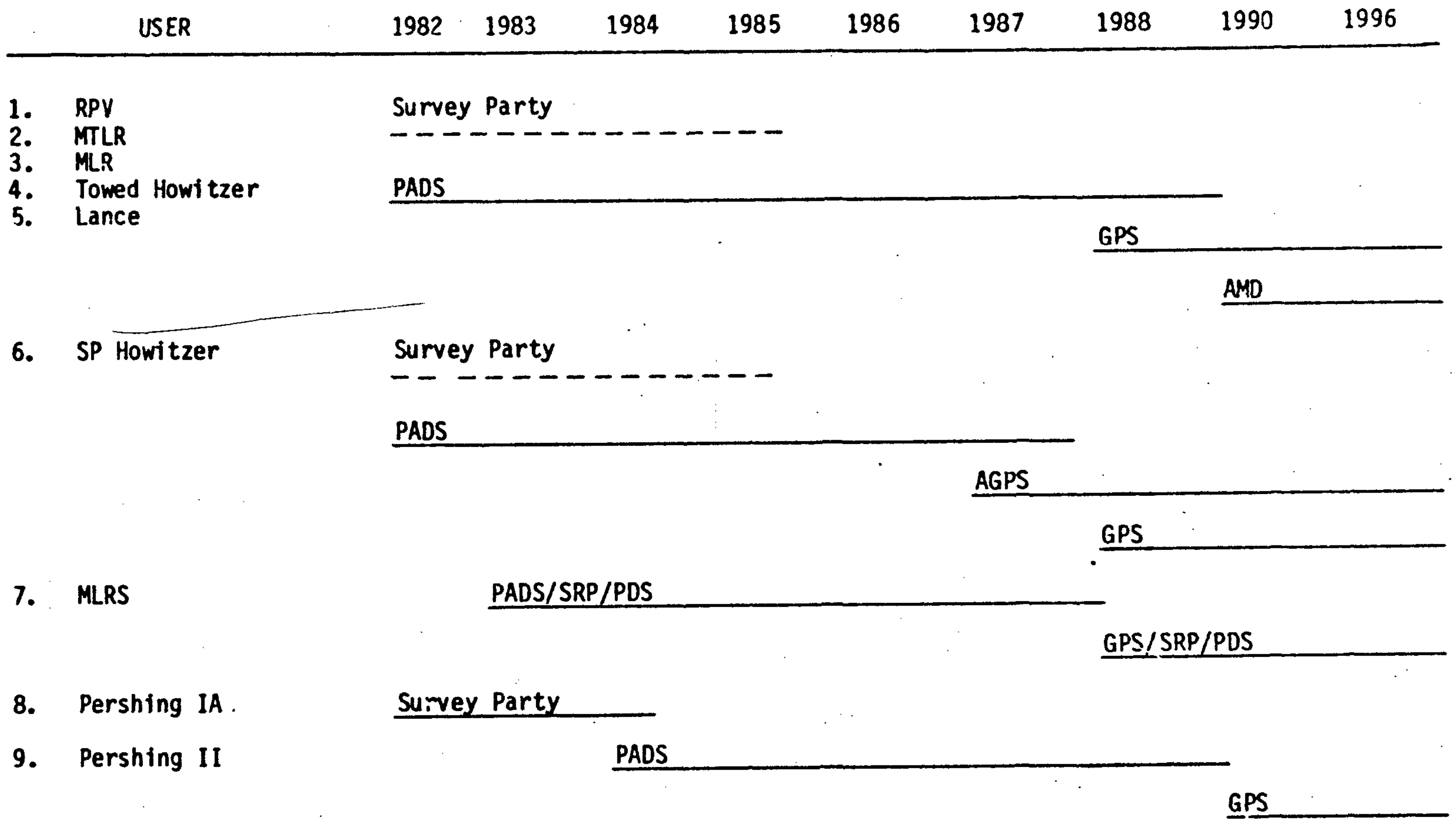
(2) PLRS/PJH. The PLRS DT/OT testing concluded in January 1982. Test data indicates that the system met its horizontal positioning requirement of 20-30 meters (CEP), however, the accuracy of any one point may vary considerably because of the number of relays used and other factors. The PJH system is a derivation of the PLRS and will not be tested until FY 87.

(3) GPS. The GPS DT/OT cycle will start in February 1983. Therefore the only data available is from OT 1 and a limited evaluation at Fort Sill. The system did not meet user requirements during OT I (26 meters CEP obtained, versus 8.5 meters CEP required). There were several problems with performance of the user units and the control segment. In contrast, data from the informal evaluations at USAFAS later in 1979 was as follows: horizontal position 6.31 meters CEP; vertical position 3.62 meters PE. It appears that some of the OT I problems were corrected prior to the USAFAS evaluation. The developer has conducted other informal evaluations since that time and has a high degree of confidence that system performance will exceed requirements.



NOTE: Dotted line indicates reduction in number of systems required as new system is fielded.

Figure 6-1. System architecture for PLRS/PJH/AMD users



NOTE: Dotted line indicates reduction in number of systems required as new system is fielded.

Figure 6-2. System architecture for GPS/AMD users

USER	1982	1983	1984	1985	1986	1987	1988	1990	1996
Sound Ranging/WLR	Survey Party								
	PADS								

Figure 6-3. System architecture for PADS users

APPENDIX A

Fire Support Mission Area Analysis (FSMAA)

Pages 4-53 through 4-59, Section VII, Target Acquisition Survey (U) Chapter 4, Target Acquisition, Phase II (Level II) Report, FSMAA are extracted as Appendix A to this report.

Section VII. TARGET ACQUISITION SURVEY (U)

4-VII-1. BACKGROUND

a. (U) This section addresses in general terms the adequacy of division level survey to support the target acquisition mission. For most sensors, target location accuracy is a direct function of the location accuracy and directional control of the sensor.

b. (U) The subsequent paragraphs discuss general survey requirements and the capability to meet those requirements. Deficiencies are identified and opportunities to minimize those deficiencies are presented.

4-VII-2. ANALYSIS

a. (U) Field artillery cannon, rocket, and missile systems are not the only systems within the corps area which need survey control. Air defense systems, SIGINT systems, and mortars require both location and directional information for radars, launchers, direction finding equipment, jammers, and unattended ground sensors. For some, a compass direction and map spot location is sufficient. But as systems with greater inherent accuracy capability are fielded, an increased demand for survey systems is expected. Future information analysis and processing systems, such as the All Source Analysis Center, portend a requirement for a common grid throughout the corps zone as a basis for correlating location data from multiple sources (US Air Force, SIGINT, MTI Radar, etc.).

b. (U) Survey Equipment.

(1) (U) Conventional Survey Parties. Conventional survey parties are equipped with steel tapes, theodolites, an azimuth gyroscope, and DM60 infrared distance measuring equipment (DME). Average rates of survey are shown below:

Tape and theodolite only	1 km/hr
DME party	2 km/hr

The SIAGL requires at least 30 minutes to provide an azimuth. The DM60 can measure distances up to 2,000 meters, requiring about 10 minutes per reading. A conventional party consists of 5 personnel.

A.2

(2) (U) Position and Azimuth Determining System (PADS). PADS provides a significantly improved survey capability for the 1986 force. Figure 4-33 summarizes its capabilities. The engineer design equipment in tests has attained a general horizontal accuracy of about 3 meters CEP and 0.3 to 0.6 mils azimuth accuracy. Mounted in a jeep, the system can travel at about 20 km/hr and requires about 10 minutes to emplace a three survey point battery position. The rate of survey is dependent upon the terrain and number of points to be installed. The system can be transported while still mounted and operational in a CH-47 helicopter and can be quickly dismounted and placed into an OH-58 helicopter. A PADS party consists of two personnel. PADS will be fielded starting in 1982.

POSITION AND AZIMUTH DETERMINING SYSTEM (PADS)

CAPABILITIES

- ALL WEATHER, DAY, NIGHT
- 6-10 km/hr SURVEY RATE
- WEIGHT: 316.5 lbs
- HORIZONTAL ERROR: LESS THAN 10 M(CEP)
- VERTICAL ERROR: LESS THAN 5 M(PE)
- AZIMUTH ERROR: LESS THAN 1 mil(RMS)

Figure 4-33. (U) PADS Capabilities.

c. (U) Survey Capability.

(1) (U) As a Battlefield Research Project, a group of Field Artillery School Advanced Course students, sponsored by the Counterfire Department, conducted a map exercise evaluation which compared conventional survey capability with an enhanced capability of mixed conventional and PADS parties. The composition of parties for each case is as follows:

COMPARISON OF SURVEY PARTIES

UNIT	BASE CONVENTIONAL	TEST CONVENTIONAL	TEST PADS
DS Battalion	2	1	1
Division GS Battalion	3	1	1
Non-Divisional GSR Battalion	3	1	1
Division Artillery	6	3	3

Using the SCORES Europe I, Sequence 2A, Scenario, the students used fixed survey rates (degrading for nighttime) to examine the capability of the survey parties to keep up with relocating units during the 48-hour period. As shown in figure 4-34, conventional parties failed to close about 30 percent of the divisional and non-divisional artillery positions required, whereas with the mix of parties with PADS, almost all positions were surveyed with reduced waiting time.

BATTALION LEVEL SURVEY

MIX	REQUIRED POSITIONS	POSITIONS CLOSED	NO WAIT TIME	AVG WAITING TIME (MINS)
CONVENTIONAL ONLY	131	92	10	100
CONVENTIONAL AND PADS	135	133	80	54

Figure 4-34. Battalion Level Survey.

Division artillery survey parties provided control to the general vicinity of each field artillery battalion as top priority and then provided survey for radars and sound bases. The exercise did not consider extending survey to RPV launchers, SOTAS ground beacons, mortar locations, SIGINT systems, or air defense systems. Even with this reduced load, the average waiting time experienced for survey was over 27 hours using six conventional parties and over an hour for the three PADS and three conventional parties, as shown in figure 4-35.

A 4

DIVISION ARTILLERY SURVEY

TYPE PARTIES	ESTIMATED AVERAGE WAIT TIME
CONVENTIONAL ONLY	27 hr 30 min
CONVENTIONAL WITH PADS	1 hr 13 min

Figure 4-35. (U) Division Artillery Survey.

The student group did not aggregate the number of positions not surveyed before the element had to move. In general, the survey system, even with PADS, was only marginally capable of meeting basic field artillery requirements. The conventional system was inadequate. Little excess time was available to devote to target acquisition systems.

(2) (U) A separate map exercise was conducted by a Combat Development Survey Staff Officer at Fort Sill in April 1980 to roughly estimate the total distance of a one time survey for all subscribers within a division slice. The estimates resulting from this exercise are shown in figure 4-36. The estimated total distance of about 1,700 km roughly reflects the distance requirement for a one time, fixed position survey. It does not include survey associated with relocation nor for moving from one general task to another. It does not reflect an optimized survey plan which, with extensive coordination, could reduce the distance through planning.

(3) (U) Including three non-divisional artillery battalions, about 16 PADS are expected to be within the division area. Assuming centralized control of PADS, full knowledge of the general location of all the positions to be surveyed, and coordination between the artillery surveyors and the various elements requiring survey, it still is apparent that timely survey data cannot be made available at all required locations. Figure 4-37 shows the time required to do a one time survey of a division slice for varying numbers of PADS, assuming that 1,700 km is an approximate total distance required as discussed above.

ONE TIME DIVISION AREA SURVEY

SURVEY REQUIRED (UNIT)	SURVEY DISTANCE (KM)
DIVISION ARTILLERY	259
TGT AQN BN	58
DS BN (3x8) (3 ea)	540 (180 ea)
GS BN (MLRS WITH BTRY)	90
NON-DIVISIONAL CANNON BN (3 ea)	225 (75 ea)
NON-DIVISIONAL MLRS BN	90
MORTARS (TOTAL)	170
SIGINT	106
SOTAS	60
AIR DEFENSE	65
TOTAL	1,673

Figure 4-36. (U) Division Slice Survey Requirement.

DIVISION AREA SURVEY TIMES

NO. OF PADS	DIVISION SURVEY TIME (HR) BASED ON SURVEY RATE 3 KM/HR	6 KM/HR	10 KM/HR
5	113	57	34
10	57	28	17
15	38	19	11
20	28	14	9

BASED ON 1,700 KM SURVEY

Figure 4-37. (U) Division Survey Times.

The 16 PADS could do the job in 10 hours at best, but it is unlikely that sufficient coordination and control would exist on a changing battlefield to accomplish even that.

(4) (U) During October and November 1980, one PADS was used to survey 1,250 points covering over 724 km (450 miles) at the National Training Center at Fort Irwin, CA. The task was accomplished in 19 days, working an average of 7 hours per day for 17 days. The average rate of survey for all days was 6 km/hour, with the best being 103 km (32 points) in 5 hours (20.6 km/hr). On 11 of the 17 days, the daily rate was between 3 and 6 km/hr. Although this exercise was administrative, it is worth noting that a well trained conventional team would have required about three and a half months or longer to complete the job.

DEFICIENCIES 4-VII-3.

a. (U) The division survey capability is inadequate to meet the needs of fire units, target acquisition and intelligence sensors, meteorlogical stations, and air defense units.

b. (U) The conventional survey system is manpower intensive, slow, and archaic.

OPPORTUNITIES 4-VII-4.

a. (U) Near Term.

(1) (U) Position Location and Reporting System (PLRS). PLRS is a time division multiple access UHF network which provides position locations (20-100 meter CEP), position navigation information, a digital interchange to assist in command and control, and network management. The system does not provide directional control. PLRS provides for up to 370 users in a division. PLRS will be fielded in the 1986 time frame. (Materiel)

(2) (U) North Finding Module (NFM). Technology for a small, lightweight, accurate, low-cost north finding module is available for near term production. This system could be used with the PLRS (above) or with the Global Positioning System (below) to provide adequate directional control and general position location (50 meter CEP). (Materiel)

A1

TARGET ACQUISITION SURVEY DEFICIENCIES

- **DIVISION SURVEY CAPABILITY IS INADEQUATE**
- **CONVENTIONAL SURVEY IS MANPOWER INTENSIVE AND SLOW**

Figure 4-38. (U) Deficiencies.

(3) (U) Global Positioning Equipment (GPS). The GPS is a space-based global system which will provide a predicted location accuracy of 8 meters CEP for horizontal and vertical control. It must be supplemented by an azimuth device (such as the NFM above) for directional control. System fielding for Army is dependent upon the PLRS fielding. (Materiel)

(4) (U) The above near term devices, coupled with PADS, could turn survey into a user operated system that could place sensors, weapons, and targets on a common grid in near real time. The potential manpower savings and increased total system effectiveness would be significant. (Materiel, Force Structure)

b. (U) Far Term. A light-weight, accurate on-board azimuth determining system and location device would decrease the dependence upon external survey control. Such a system could be used by individual target acquisition devices, mortars, howitzers, MLRS, missiles, DF equipment, and ADA systems. (Materiel)

A-8

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A-9

APPENDIX B
Survey CEP (SCEP) Description

B-1. Description

a. Total SCEP is the amount of "on-target" error introduced by the positioning and orientation errors of an FA system when that system becomes involved in a subsequent fire mission. Positioning and orientation errors are broken into the following three categories:

(1) Horizontal. This is the ground plane location error for the FA system. Horizontal error directly translates into "on-target" error. Since horizontal error is measured in circular terms, CEP, it is assumed that horizontal error contributes equally in range-direction and deflection-direction to the "on-target" error. (See figure B-1).

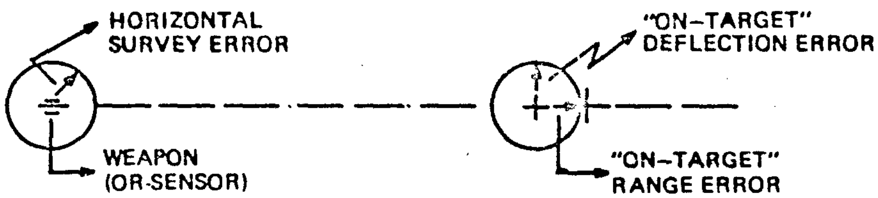

Figure B-1. "On-target" transfer of horizontal survey error

(2) Azimuthal. This is the orientation error of the FA system. Azimuthal error is assumed to contribute "on-target" error in the deflection-direction. The amount of deflection error contributed is a function of system-to-target range. (See figure B-2). For each FA system considered in analysis, a median system-to-target range was selected.

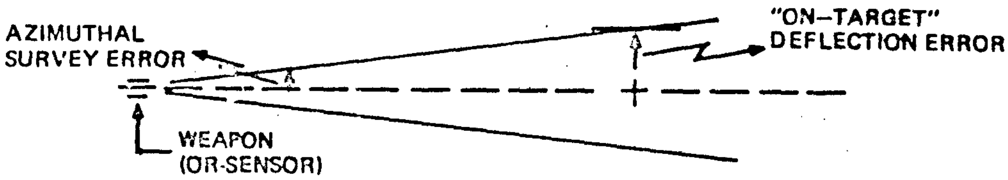

Figure B-2. "On-target" transfer of azimuthal survey error

(3) Vertical. This is the altitude or vertical location error associated with a survey system. Vertical error is assumed to contribute "on-target" error in the range-direction. The amount of range error contributed is generally a function

of the projectile's angle of fall on a subsequent fire mission. (See figure B-3). An exception is made for counterfire radar (MLR and WLR) where the amount of range error contributed is a function of the enemy projectile's ascent angle at the point of radar intercept.

A thirty-seven (37) degree angle of fall was assumed for most SCEP computations to simplify the analysis. This represents a typical, if not median, friendly artillery trajectory at the impact area.

A twenty (20) degree angle of ascent was assumed for counterfire radar SCEP computations. This represents a typical enemy artillery trajectory at the point of radar intercept. This assumption is especially appropriate for WLR which acquire artillery only. The same angle was used for MLR because these radar can also acquire artillery.

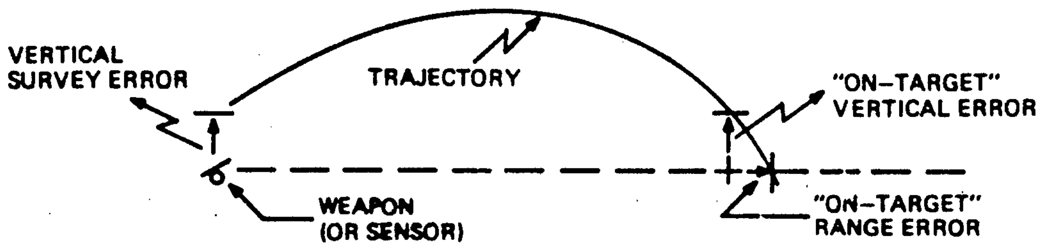

Figure B-3. "On-target" transfer of vertical survey error

b. Individual error components of the SCEP are those associated with equipment and procedures employed in the positioning and orienting of an FA system. Since target data is often transferred throughout the division area, survey errors are accumulated from division survey control points (SCP) forward to survey users. This accumulation of errors includes the error inherent in survey techniques which provide survey control to the user as well as transfer errors. Transfer errors account for additional errors introduced by the positioning and orientation of an FA system given survey control. For example, an azimuthal transfer error is introduced when a firing battery's tubes are layed. This transfer error is in addition to survey control error inherent in the battery's orienting line. To make a fair comparison of survey alternatives, transfer errors are included in SCEP computations because different survey alternatives require different transfer techniques. Some alternatives eliminate transfer requirements.

B-2. Algorithm

a. Inputs used to compute a SCEP were as follows:

K -- Weapon-to-'arget or (sensor-to-target) range (KM)

θ -- Projectile angle of fall in impact area

H_C -- Horizontal control error (CEPm)

H_X -- Horizontal transfer error (CEPm)

A_C -- Azimuthal control error (PEm)

A_X -- Azimuthal transfer error (PEm)

V_C -- Vertical control error (PEm)

V_X -- Vertical transfer error (PEm)

b. Total horizontal, azimuthal, and vertical errors (H_T, A_T, and V_T, respectively) were derived by root sum squaring control and transfer errors as follows:

$$H_T = (H_C^2 + H_X^2)^{1/2}$$

$$A_T = (A_C^2 + A_X^2)^{1/2}$$

$$V_T = (V_C^2 + V_X^2)^{1/2}$$

c. Using standard accuracy conversion formulas (PE = .6745 SD and CEP = 1.1774 SD), the following equation was derived to convert H_T to "on-target" range probable error and "on-target" deflection probable error (R_H and D_H):

$$R_H = D_H = .5729 \ (H_T)$$

Azimuthal error A_T was translated to "on-target" deflection probable error (D_A) as follows:

$$D_A = K \ (A_T)$$

Vertical error V_T was translated to "on target" range probable error (R_V) as follows:

$$R_V = (V_T) \ \cot(e)$$

d. Total "on-target" range probable error (R_T) and "on-target" deflection probable error (D_T) was determined by root sum squaring the appropriate "on-target" error components as follows:

$$R_T = (R_H^2 + R_V^2)^{1/2}$$

$$D_T = (D_H^2 + D_A^2)^{1/2}$$

e. Again, using standard accuracy conversion formulas, total "on-target" errors were converted to standard derivation form as follows:

$SD_R \;=\; R_T/.6745$

$SD_D \;=\; D_T/.6745$

and finally the SCEP could be computed as an "equivalent" CEP as follows:

$SCEP \;=\; .5887\ (SD_R + SD_D)$

f. An "equivalent" CEP is actually only an estimate of the "true" CEP. For a large max-to-min ratio the accuracy of an "equivalent" CEP estimate is somewhat degraded (see figure B-4). For consistency, however, this SCEP estimation technique was used throughout the analysis. The error inherent in this technique is not significant enough to detract from insights gained by relative comparisons.

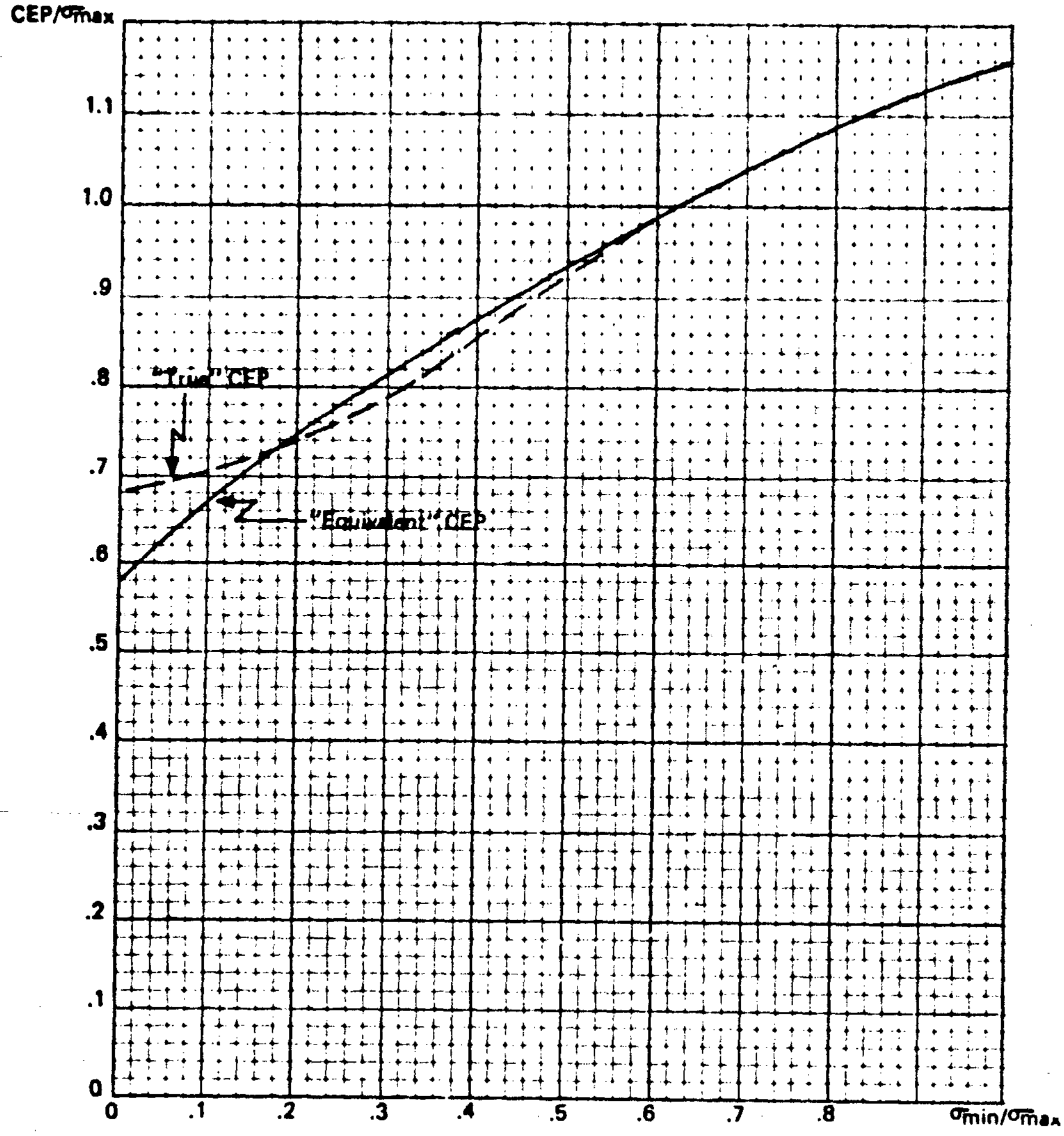

Figure B-4. Comparison of "true" CEP and "equivalent" CEP

APPENDIX C

FRCEP AND ORCEP METHOLOGY

C-1. GENERAL METHODOLOGY. A Monte Carlo model was designed to compute FRCEP (First Round CEPs) and ORCEP (One-Round Adjust CEPs). Each Monte Carlo procedure considered the random error inherent in the ground observer's self-location technique as well as random errors in his ability to measure distance and direction to the target center. These errors, coupled with weapons system delivery errors, contributed to the resultant First Round errors. The observer's ability to determine azimuthal and distance differences between target center and first round impacts, along with weapon system precision errors and inherent error in the adjustment procedure itself, contributed to the resultant One-Round Adjust errors. Ten thousand Monte Carlos were repeated for each FRCEP/ORCEP computation. Individual First Round errors and One-Round Adjust errors were then statistically combined to express FRCEP and ORCEP in terms of CEP in meters.

C-2. INPUTS AND ASSUMPTIONS.

a. There were basically three types of inputs used by the Monte Carlo simulation to produce the results used in this study:

(1) Inputs which remained constant throughout the analysis.

(2) Inputs which varied with each of the four ground observer types analyzed.

(3) Inputs which varied with each simulation.

b. Inputs which remained constant throughout the analysis include the number of rounds fired for adjustment (one), the number of rounds fired in the subsequent FFE volleys (four), and the accuracy to which an observer may recognize a target's center (assumed perfect). Throughout the analysis, a gun-target-observer apex angle of 15° was assumed. The remaining "constant" mission parameters, such as gun-target range and weapon system delivery errors (precision and MPI), are the same, with some exception, as the "standard" artillery mission parameters described in Appendix D. The obvious exception is that the fire technique is not MET+VE unadjusted, but, rather, observer adjust. Other minor exceptions are discussed in paragraph 5-4c.

c. The only input which varied with each observer type analyzed was the observer-target (OT) range. For observers without the GLLD, a 2 km OT range was used. For all other observer types, a 3 km OT range was used. This is consistent with OT ranges used in SCEP computations. Paragraph a of Appendix E discusses the OT range selections.

d. Inputs which varied with each simulation included the observer's self-location accuracy, azimuthal control accuracy, azimuth adjust accuracy, and distance-measuring accuracy. Self-location accuracies and azimuthal control accuracies were the same as the horizontal and azimuthal control accuracies used to compute SCEP for the various survey methods. Distance-measuring accuracies used to compute SCEP for the various survey methods. Distance-measuring accuracies of the various laser range finders considered are described in paragraph 3-2c and 3-2d of the main report. The accuracy with which an observer determined the angular measurement from the initial adjust round's center of impact to the target center is termed azimuth adjust accuracy. Ground observers equipped with a compass for orientation were assumed to have an azimuth adjust accuracy of 10 meters PE. Ground observers equipped with the AMD or the NSG were credited with an improved azimuth adjust accuracy of 5 meters PE.

APPENDIX D

STANDARD ARTILLERY MISSION

D-1. General Comments. In deciding upon a "standard" artillery mission, consideration was given to the fact that some parameters may be extremely critical to the resultant expected fractional casualties (EFC) without having a significant bearing on relative comparisons of EFC. For instance, target "hardness" or the vulnerability of target area elements is critical to EFC. Certainly, for similar artillery attacks, the EFC will be much higher against personnel standing than for armored personnel carriers. Note, however, that the ultimate use of EFC is to make relative comparisons of artillery effectiveness given various SCEP, FRCEP or ORCEP. For similar missions, these relative comparisons would be approximately the same for personnel standing as for armored personnel carriers. For simplification, parameters of this nature may therefore be selected rather arbitrarily without degrading the analysis. Other parameters, however, such as the size and geometry of both the target area and volley spread and factors affecting the system delivery errors do have a bearing on relative comparisons. These parameters must be carefully selected.

D-2. Mission Parameter Selections

a. The M109A3 self-propelled howitzer was selected as the weapon type because it is the predominant cannon system. Also, its ballistic characteristics are similar to other 155mm cannon systems and somewhere between those of the 8-inch and 105mm cannon systems.

b. The M483A1 projectile was selected because future artillery systems will be expected to fire a high proportion of dual-purpose improved conventional munitions.

c. To represent the 3 X 8 split batteries of Division 86, four-gun volleys were fired. The Battery Computer System (BCS) volley spread algorithm was used to determine appropriate aimpoints for the individual rounds.

d. To avoid classificaton, the number of volleys fired, the target type (e.g., personnel, trucks, armored personnel carriers) and terrain (e.g., open, wooded, urban) are not mentioned. A great deal of variation in these particular parameters will not affect relative comparisons of artillery effectiveness where either SCEP, FRCEP or ORCEP is varied. Selections were made representative of a typical artillery mission.

e. The unadjusted fire technique was chosen because it is the type of fire for which SCEP is important. In the adjusted method of delivery, the observer may eventually "adjust-out" most of the survey errors.

f. MET + VE was selected as the most common type of unadjusted fire.

g. Figure E-1 illustrates the way SCEP contributes to the resultant EFC casualties. The total mean-point-of-impact (MPI) error is composed of SCEP, weapon system MPI error and target location error (TLE) other than SCEP. The relative loss in effects caused by SCEP decreases as total MPI error increases. MPI error conditions were therefore parameterized.

h. In some situations, practically all of the total target location error is composed of SCEP (i.e., positioning and orientation of the sensor caused the target location error). In other situations, "additional" errors are introduced by the sensor itself. For "best-case" MPI error conditions, no "additional" errors contributed to the MPI error; for "worst-case" MPI error conditions, an "additional" error of 50m CEP was assumed. The weapon system MPI error associated with a MET + VE mission is sensitive to the "staleness" of the meteorological data and the gun-target range. A single, median gun-target range of 12 km (Charge 7) was selected. For "best-case" MPI error conditions, an hourly met message was assumed to represent the responsiveness of the Meteorological Data System (MDS) over limited periods of time. For "worst-case" MPI error conditions, one met message every two hours was assumed to represent the MDS responsiveness over extended periods. Interestingly, these "worst-case" MPI errors for the median 12 km gun-target range closely approximate the near-maximum gun-target range MPI errors given hourly met messages.

i. Target size, a critical parameter which varies considerably, was also parameterized. Circular target areas of both 50 meter and 150 meter target radii were analyzed.

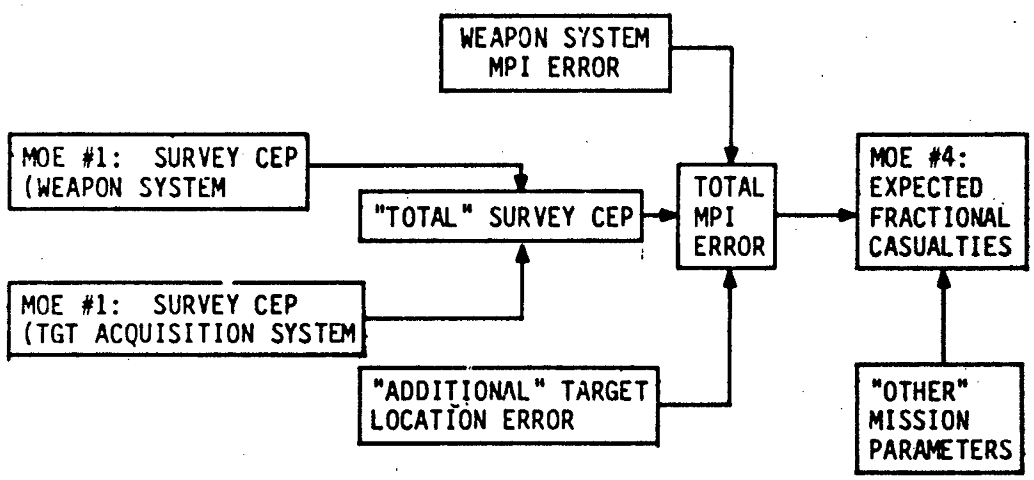

Figure D-1. SCEP's influence on artillery effectiveness

APPENDIX E

SCEP INPUTS

E-1. Rationale for use of the input values listed in the SCEP value tables, Chapter 5, are listed in subsequent sub-paragraphs.

a. Ground observers will select locations that offer the best line-of-sight conditions available to support manuever units. For this reason, terrain has a major influence on the "median" observer-target (OT) range. OT ranges of 3 km for observers with GLLD and 2 km for observers without GLLD were selected as median OT ranges given a typical terrain. The difference in OT ranges is due to the difference in responsibilities. The observer without GLLD supports platoon-level manuevers. Thus, he has less latitude in selecting a location than the observer with GLLD which supports company-level manuevers. Based on the responsibilities of ground observers in the FIST V and the sound/flash observation section, these observers are expected to have a flexibility in selecting a location similar to the ground observer with GLLD. Therefore, a 3 km OT range was assumed median for these observers.

b. This is the accuracy required for the FA system of interest. The value was extracted from table 4-2.

c. Given two reference points and an azimuth measuring capability, this is a system's self-location accuracy when resection is performed. Resection is accomplished by measuring an azimuth to each of the two known points. Back-azimuths from each of the two known points may then be intersected. The point of intersection is the system's estimated location. The accuracy value was derived by Monte Carlo simulation. Major assumptions inherent in the simulation are:

(1) Both reference points are located to an accuracy of 20m CEP.

(2) Both reference points are located 2 km from the system's position.

(3) A 90° apex is formed by the reference points and the system's position.

The accuracy of resection strongly depends on the accuracy of the azimuth measuring instrument used. Various instruments considered were:

COMPASS -- M2 Compass (see para 3-2.b)

AC -- M2A2 aiming circle (see para 3-2.e)

AMD-3 -- AMD in its most responsive, least accurate mode (see para 3-2.i)

AMD-2 -- AMD in its mid-responsive, mid-accurate mode (see para 3-2.i)

AMD-1 -- AMD in its least responsive, most accurate mode (see para 3-2.i)

NSG -- FIST vehicle's north seeking gyrocompass (see para 3-2.g)

d. The azimuth measuring accuracy of an M2 compass. (see para 3-2.b)

e. When accurate vertical survey control is not available, altitude is determined by interpolation of contour lines on a map. The accuracy of this process is assumed to be 10m PE. For a reasonably accurate horizontal location in most terrains, this would be a reasonable estimate. For steep, mountainous terrain, this process would be less accurate---especially when horizontal location errors are large.

f. The azimuth measuring accuracy of the AMD operating in its most responsive, least accurate mode. (see para 3-2.i)

g. Given two reference points and a distance measuring capability, this is a system's self-location accuracy when a two-point laser range finder (2PT LRF) method is employed. The 2PT LRF method is accomplished by measuring a distance to each of the two known points. Using the known points as center points and distances as radii, arcs may then be intersected in the system's general vicinity. The point of intersection is the system's estimated location. The accuracy value was derived by Monte Carlo simulation. Major assumptions inherent in the simulation are:

(1) Both reference points are located to an accuracy of 20m CEP.

(2) Both reference points are located 2 km from the system's position.

(3) A 90° apex is formed by the reference points and the system's position.

The accuracy of the 2PT LRF method strongly depends on the accuracy of the LRF used.

Various LRF's considered were:

HHLR2 -- an inaccurate hand-held LRF selected to represent HHLR accuracy derived from HHLR OT II results. (see para 3-2.c)

HHLR1 -- an accurate hand-held LRF selected to represent HHLR accuracy derived from USAFAS HHLR testing and experience. (see para 3-2.c)

GLLD -- Ground locator laser designator. (see para 3-2.d)

h. Given one reference point, an azimuth measuring capability and a distance measuring capability, this is a system's self-location accuracy when a polar plot is performed. A polar plot is accomplished by measuring an azimuth and a distance to a single known point. The system's estimated location is then derived by plotting the measured distance along a back-azimuth from the known point. The accuracy value was derived by Monte Carlo simulation. Major assumptions inherent in the simulation are:

(1) The reference point is located to an accuracy of 20m CEP.

(2) The reference point is located 2 km from the system's position. The accuracy of a polar plot strongly depends on the accuracy of the azimuth measuring instrument and the laser range finder (LRF) used. LRF's considered are the same as those listed in note g. Azimuth measuring instruments considered were:

COMPASS -- M2 Compass (see para 3-2.b)

AMD-3 -- AMD in its most responsive, least accurate mode (see para 3-2.i)

NSG -- FIST vehicle's north seeking gyrocompass (see para 3-2.g)

i. Based on the following two considerations, a compromise value of 150m CEP was used to estimate map-spotting self-location accuracy.

(1) The self-location accuracy objective in USAFAS map reading instructions is 100m CEP. Instructors feel the goal is reasonable, but admit that students sometimes fall short of the goal.

(2) Available test data from a variety of tests indicate that approximately 200m CEP may be a more reasonable estimate of map-spotting accuracy. These test results are listed below:

FO's Ability to Map Spot His Location

Source	Error in Self-Location (CEPm)
WESTEA-FO	213
ARTS-TEA-78	340
HELBAT-1	146
HELBAT-2	93
HELMST	204
GLLD OT II	155
AMSAA/CDEC	290

Part of the reason for large variations in the results are differences in terrain, terrain familiarities, and map-reading proficiencies.

j. A gun-target range of 12 km was selected to represent median conditions for cannon artillery. Selecting a longer GT range would magnify the contribution of azimuthal survey errors. Note, however, that larger weapon system delivery errors associated with longer GT ranges decrease mission effectiveness sensitivity to survey errors in general. The somewhat counter-balancing effect of these observations suggests that parameterizing GT range is not critical to a mission effectiveness comparison. For this reason, a single GT range was selected to simplify analysis.

k. This represents the total error accumulated as survey control is extended from the Division Survey Control Point (SCP) to the survey user. The accuracy of PADS (see para 3-3.b) was used once to represent the 4th order extension from the Division SCP to the Battalion SCP. The accuracy of PADS was used a second time to represent the 5th order extension from the Battalion SCP to the survey user. Note that root sum square, not strict addition, was used to combine errors. Note also, that the same azimuthal control accuracy of, .4 mil PE was used for both 4th and 5th order survey. This is because PADS 2-point azimuth determinations do not require initial azimuthal control. The fifth order number was also used for the S/F Obsn Section because it was assumed that a second iteration of PADS survey is required to reach the OP.

l. Individual gun displacements relative to the battery orienting station are estimated by hasty techniques such as pacing. The accuracy of this process was assumed to be 10m PE.

m. A battery orienting azimuth must be transferred to the individual guns. This is the accuracy of the transfer process using an M2A2 aiming circle and the weapon sighting system (see para 3-2.e).

n. Vertical gun displacements relative to the battery orienting station/battery/platoon center are presently estimated by pacing, etc. The battery computer system, now being fielded, includes a capability to compute individual gun positions given a direction, distance and vertical angle from the OS to each position. Angles are measured by the aiming circle and distances are determined by pacing, calibrated wire, etc. The accuracy of this process was assumed to be 1m PE.

o. The APGS (or SRP/PDS) requires horizontal and vertical survey control be provided externally in the form of initialization and update points. The accuracy of this control depends on the providing system. For 5th order initialization accuracies see para 3-3.b. For PJH initialization accuracies see para 3-4.a. For GPS initialization accuracies see para 3-4.c. Initial azimuthal control is not required, since each APGS (or SRP/PDS) has its own azimuth measuring capability.

p. This is the accuracy to which the APGS or SRP/PDS extends survey from initialization points to firing positions (see para 3-2.h or 3-2.f).

q. The azimuth measuring accuracy of the M2A2 aiming circle (see para 3-2.e.

r. The azimuth measuring accuracy of the AMD operating in its mid-responsive, mid-accurate mode (see para 3-2.i).

s. This accuracy is associated with the PLRS or PJH (see para 3-4.a or 3-4.b).

t. This accuracy is associated with the GPS (see para 3-4.c).

u. Based on survivability offsets from the FLOT as well as lateral displacements of both the Q36 radar and enemy mortar/artillery, a 15 km radar-to-tube range is reasonably typical for the Q36 radar.

v. In addition to the error inherent in a radar's orienting line (OL) error is also introduced when the radar is layed on the OL by boresighting. The accuracy of the boresighting procedure was estimated to be .6ɱ PE. This value has never been tested, but the nature of equipment and processes employed indicate that boresighting is more accurate than azimuth transfer with an M2A2 aiming circle (1.2ɱ PE) and less accurate than azimuth transfer with a T16 theodolite (.09ɱ PE). Should the AMD be successfully mounted on the radar, the .6ɱ PE of boresighting would not be applicable for cases where AMD is employed. If technical problems such as wind vibrations can be solved, an improved accuracy would be realized; if not, a dismounted AMD could determine the azimuth of the orienting line and boresighting would be employed as usual. For this analysis, the latter is assumed. This is not to say, however, that technical problems are not likely to be solved.

w. The azimuth measuring accuracy of the AMD operating in its least responsive, most accurate mode (see para 3-2.i).

x. Based on survivability offsets from the FLOT as well as lateral displacements of both the Q37 radar and enemy artillery, a 30 km radar-to-tube range is considered reasonably typical for Q37 acquisitions. It is also long range enough to illustrate the effect of orientation error.

y. The accuracy of PADS (see para 3-3.b) was used to represent the 4th order extension of survey from the division survey control point to a 4th order survey user. The accuracy for three-minute updates, used in the WLR analysis, is discussed at paragraph 3-3b(1)(b).

z. This represents the accuracy of a SIAGL operating at 35° latitude (see para 3-3.d). Assuming .03 PE per station angle (see para 3-3.c), it also represents the accuracy of the 4th order directional traverse 15 legs from a division survey control point.

aa. This is the accuracy of a 4th order astronomic observation (see para 3-3.e).

bb. A 30 km range from the remote ground terminal is reasonably typical for an RPV acquisition. It is also long range enough to illustrate the effect of orientation error.

cc. LANCE uses on-board sighting equipment and a T2 theodolite to transfer azimuthal control from the orienting line to the missile launcher. The tested accuracy of this laying procedure is .15ɱ PE. RPV sections will employ a T16 theodolite to lay the remote ground terminal (RGT). Due to similarities in on-board sighting equipment and the high degree of accuracy associated with either theodolite, .15ɱ PE was also assumed for the RPV RGT laying procedure.

dd. A median MLRS GT range of 30 km was selected in view of its capability to deliver deep fires and an anticipated large survivability displacement from the FLOT.

ee. A median LANCE GT range of 60 km was selected as typical of non-nuclear missions.

ff. This considers the possibility of equipping each SP howitzer with its own positioning equipment, such as GPS or PJH, to alleviate the APGS requirement for update points. In this instance, only the azimuthal capability of the AGPS will be used. For AGPS azimuthal accuracy, see para 3-2.h. For GPS positioning accuracies, see para 3-4.c. For PJH positioning accuracies, see para 3-4.a.

gg. Survey doctrine requires 4th order survey techniques for providing positioning data to LANCE, but it does not require that the traverse begin at a 3rd order initialization point. Since "4th-on-4th" is allowed, positioning data for LANCE will equate to 5th order accuracy when PADS is used. For further explanation of 5th order accuracies, see note k.

hh. Should 4th order directional traverse provide azimuthal control for LANCE, survey doctrine requires that 3rd order azimuth be used for initialization. In addition, the 4th order directional traverse is limited to no more than nine station angles. Since target data for LANCE is widely distributed and azimuthal control is critical to long-range LANCE missions, the initial 3rd order accuracy was root sum squared with the 4th order directional traverse accuracy. FM6-2 (JUNE 70) states that 3rd azimuthal control is accurate to ±.18₥ with 90% assurance. This equates to .07₥ PE. Assuming .03₥ PE per station angle (see para 3-3.c), the accuracy of 4th order directional traverse limited to nine station angles is .09₥ PE. Root sum squaring both error components results in a .11₥ PE.

ii. The azimuth measuring accuracy of the FISTV NSG (see para 3-2.g).

jj. For most terrains, line-of-sight limitations would preclude exceeding this radar-to-target range for most operations.

kk. PADS three-minute update accuracy is based on informal USAFAS evaluations of PADS performance. See paragraph 3-3b(1)(b) for discussion.

The accuracy of the 2PT LRF method strongly depends on the accuracy of the LRF used.